# BaPS

**B**arometric **P**rocess-**S**eparation

## System for the determination of microbial nitrogen and carbon conversion rates in soils

## User Manual

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**Explanation of symbols:**

Warning, caution, important note! Not following this might cause damages of the system or measuring errors.

Useful hints and tips.

Additional Information.

Your addressee for any inquiries regarding this subject..

**Please carefully read and understand this manual before working with the BaPS system.**

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# 1 Introduction

The **B**arometric **P**rocess-**S**eparation (**BaPS**) is a new method for the determination of microbial carbon and most of all the microbial nitrogen conversion rates in organic and mineral soils. Above all gross nitrification and gross de-nitrification rates are the most interesting.

Nitrification [SCHL 1992] is the decisive process for Nitrate dispensation in soils. So far, determinations are only possible with the very costly $^{15}N$-pool dilution technique [MOS 1993].

Nitrate has an important environmental relevance as:

- on one hand the contained Nitrogen is a major nutriment for plants,
- but on the other hand Nitrate contaminates ground und drinking water.

Nitrate and it's decay products converted in the human body are detrimental to health. A to high pollution burden, most of all in drinking water, must be avoided. In drinking water 50 mg/l is generally regarded as the limiting value, but this should already be classified as a critical value for infants.

It is well known that the Nitrate flows beneath farm lands caused by the use of fertilizers are the major source for the Nitrate contamination of the groundwater and, as a consequence, of our drinking water system. Despite the problematic measuring techniques the determination of quantity and flow of substances (mainly Nitrate) is the key for short-term decisions on how and when to use fertilizers and irrigation.

The system developed and patented by the Fraunhofer Institute for Atmospherically Environmental Research (IFU) [ING 1999] offers a simple and reliable process for the determination of gross conversion rates. Now, a verification and monitoring of nitrogen conversion in soils is possible. As the results are offered rather quick (within 5 to 12 hours) for example fertilising schedules for the same day can be set up.

This will help to optimize the use of Nitrogen fertilizer and protect the groundwater. Learning more about the nitrogen conversion rates increases the knowledge for the microbiological courses in soils and makes this system very suitable for scientific research in this field as well.

**Measuring cycle**

The BaPS measuring cycle will start in the field with taking soil samples. By using standard soil sampling rings the samples will be disturbed the least. In one BaPS unit 7 samples are analysed simultaneously. Get a typical selection of samples to receive results which are as close as possible to the realistic processes in heterogeneous soils.

Take the samples to the laboratory, preferably inside the BaPS container closed with the accessory transportation lid. In the laboratory put on the measuring head (lid with incorporated sensor fittings) and connect the sensor interface. Now, the soil samples a sealed pressure tight.

Allow the samples to obtain the required temperature. It would be best to use a thermostat with an external thermo cycle. When the system has reached temperature stability start the reading with the supplied Windows-Software.

To make a measurement the software needs some specific data. For a quick and easy to handle start up the software proposes pre-set plausible values for all required and important inputs.

During a measurement the readings and the evaluated rates are displayed online. This will allow the user to assess the accuracy and reliability of a running measurement. For a sufficient accuracy, the sensors require a minimum alteration rate. Extending the measuring time will increase the accuracy.

When the required accuracy is reached, the measurement is stopped either manually or automatically. In an automated procedure the system continuously controls the default minimum alteration rates and pre-set accuracies.

The evaluation of the readings is performed automatically. The results can be printed or exported to other Windows applications.

Find the detailed description of the measuring cycle in the chapter „Taking BaPS-readings“.

**The BaPS process is only applicable in soils which are not waterlogging. In waterlogging soils certain processes take place which cannot be determined by BaPS.**

# 2 Content of delivery

The following parts must be included in the delivery::

- ✔ This manual
- ✔ CD-ROM with BaPS software
- ✔ BaPS container
- ✔ BaPS measuring head (lid with sensor fittings)
- ✔ BaPS transportation lid
- ✔ BaPS thermo box
- ✔ 6 fly nuts, 1 spare fly nut
- ✔ $CO_2$ sensor
- ✔ Pressure sensor
- ✔ 7 stainless-steel sampling rings
- ✔ 14 rubber covers for sampling rings
- ✔ BaPS sensor interface including 3 not removable cables
- ✔ Vacuum tight syringe, 10 ml, incl. spare needle
- ✔ 2 quick-lock couplings for the tempering fluid
- ✔ 1 plug-kit, 4-pin, for external temperature probe
- ✔ 3 sealing rings
- ✔ 20 septum, silicone, ∅ 12 mm
- ✔ Interface cable
- ✔ Mains power supply cable
- ✔ Sealing grease
- ✔ Fork wrench, metric size 13/17

# 3 Initial operation

Read chapter 5.2. for the installation of the software (page 26).

## 3.1 Connecting sensors

Remove the cables from the $CO_2$- and the pressure sensor and screw them onto the proper fitting on the measuring head. Firmly tighten both sensors. Please be careful not to damage the temperature sensor on the inside of the lid.

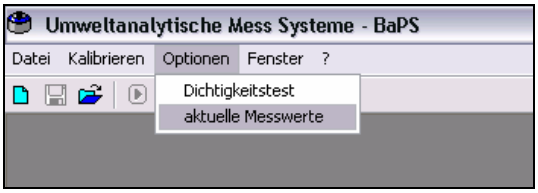
Place down the lid as in above picture and connect the three signal cables.

Now also connect the power supply cable.

Connect your PC and the sensor interface with the supplied interface cable.

## 3.2 Find the COM port

Turn on the sensor interface (green LED must be on) and start the BaPS software on your PC. In the software menu, select the function Datei ⇐ Eigenschaften.




The menu "Eigenschaften" will open. Either select the COM Port by yourself or browse for the COM Port in the menu "Verbindung". Confirm your selection by pressing the button „Übernehmen“.

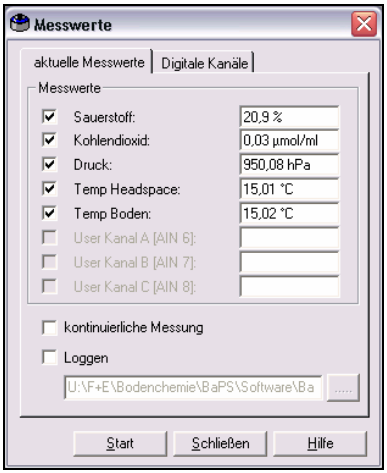
If you cannot connect to the sensor interface check the following:

- ➜ Is the sensor interface connected to the PC with the interface cable?
- ➜ Did you use the appropriate cable?
- ➜ Are the plugs inserted properly?
- ➜ Is the sensor interface turned on?
- ➜ Is the COM Port used by another application?

(please also read chapter "Malfunction diagnosis")

## 3.3 Initial function test

Now carry out the first functional test. Wait for 2 minutes after turning on the sensor interface for stabilisation. In the software menu select "Options" ⇐ "aktuelle Messwerte". The window "aktuelle Messwerte" will open and plausible readings should be displayed.




Close this window as in all Windows programs by clicking on the x in the upper right corner or on the "close" button.

## 3.4 Connecting a thermostat

### 3.4.1 Cooling circuit

If you have a thermostat with an external cooling circuit connect the two supplied female quick-lock couplings to the tubes of your thermostat. The couplings will fit on tubes with an interior diameter of 6 ... 6,2 mm.

Plug on the tube couplings to the male couplings on the BaPS container. Press in firmly until the coupling clicks in. If the tubes are removed or in case the couplings get loose internal valves will prevent cooling liquid from leaking out.

Push down the metal clip on the coupling to remove the tubes.

**Depending on the type of thermostat the external circuit must be closed for starting operation. In this case, connect the thermostat with the BaPS couplings before turning on the thermostat.**

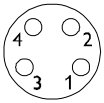
Please observe the instructions in the manual of your thermostat!

### 3.4.2 External temperature sensor

If your thermostat has a controller option for an external PT100 temperature sensor, the internal BaPS soil temperature sensor could be used. Connect it with the 4-pin socket on the backside of the BaPS sensor interface. Please make your connecting cable with the supplied cable kit referring to the following connection scheme (four-wire principle):

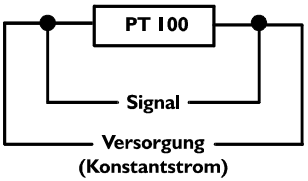
Pin 1 = Supply + Pin 3 = Signal –

Pin 2 = Signal + Pin 4 = Supply -




Steckerbelegung
Lötseite

Measuring principle for PT100, 4-wire:



# 4 Hardware description

## 4.1 Incubation container

The incubation container is made of anodised Aluminium. This material combines a good thermal conductivity with high firmness and little weight.

The soil samples are taken with the seven supplied soil sampling rings (height 40,5 mm, ∅ 60 / 56 mm) and placed into the borings inside the container. For transportation, the container is covered with the transportation lid. For measurements in the laboratory the transportation lid is replaced by the measuring head. Please do not take the measuring head out to the sampling site to avoid contamination or damage!

A cooling duct for tempering the container is integrated in the base of the chamber. The tubes for the tempering fluid are connected to the plastic quick-lock couplings.

If you should not have a thermostat with external cooling, the closed container might be submerge into a water bath down to the starting of the 24-pin plug connector, but not deeper.

*Fig. BaPS in a water bath*

**Before submerging the container the lid must be closed tightly or the sensors might be damaged by permeation of water.**

**Please be careful not to damage the sealing surface for the O-ring seal.**

### 4.1.1 Sealing

**Before closing the lid be sure that the sealing surface and the O-ring seal are clean and in proper condition to assure a gas tight sealing.**

The O-ring seal is made of NBR (butadiene acrylonitrile rubber), features are shore hardness 50, gas tightness, abrasion-resistance and stability against most chemicals. Whenever the O-ring seal should have a damage, it must immediately must be replaced.

TIP **To approve the sealing the surface and the O-ring seal might be covered thinly with vacuum grease. Then, as the grease will complicate the cleaning, you must avoid contaminations even more.**

Both lids are fastened with the 6 fly nuts. For transportation it is sufficient just to screw down the nuts slightly. Before taking measurements screw down the nuts steadily and crosswise so the lid has a form-fit seat on the container. Fasten the nuts only hand-tight and do not apply force.

**INFO Note that the durability of the O-ring seal is considerably reduced by UV-radiation (sunlight). INFO**

## 4.2 The measuring head

The measuring head incorporates the sensors, the septum and the ventilator. The sensors are protected by a perforated plate on the inside of the measuring head.**Fehler! Textmarke nicht definiert.**

To prevent condensation on the sensors the measuring head must always be turned on before starting the tempering of the container. To do so, turn on the BaPS sensor interface with the mains switch after connecting the cable to the measuring head. The switch is placed on the backside of the sensor interface enclosure.

**Tempering the container with a thermostat significantly increases the chance of condensation as soil moisture will vaporise and condense on the inside of the measuring head. Therefore, always temper with small gradients to**

**allow an even temperature interchange within the container.**

**The measuring head may only be kept on the container during a measurement. Take of the measuring head immediately after a measurement to prevent condensation.**

### 4.2.1 Sensor technology

During an automatic BaPS measurement the sensors measure all required parameters. The accuracy of the determination strongly depends on the accuracy of the sensors which makes it necessarily to use high-quality sensors. A main focus was set on the stability of the signals.

In the following chapter the sensor principles are describes. The detailed technical specifications are listed in the chapter "T3chnical Specifiactions".

#### 4.2.1.1 Temperature sensor

Microbiologic processes are very sensitive to temperature. Therefore, it is necessary to have defined temperatures during measurements. Three temperature sensors for monitoring and control are used, all are PT100/1000 types with accuracy class 1/3 DIN B+ (variance <0,1K at 0°C).

Temperature is picked up in the soil as well as in the headspace. The measurement will not start unless a certain temperature stability has been achieved.

The soil temperature probe is equipped with two independent temperature sensors. One sensor can be used for external regulation, for example of an thermostat. Use the 4-pin connector on the backside of the BaPS sensor interface (see chapter "External temperature sensor"). Clean the temperature probe with a moist cloth.

**INFO Besides the requirements of the microbiological process, the good thermal stability reduces temperature related sensor inaccuracies and pressure changes. INFO**

#### 4.2.1.2 Pressure sensor

Inside the incubation container the absolute pressure is measured. The used sensor is a stainless-steel encapsulated, piezoresistive pressure transmitter with a range of 800 to 1200 hPa. The sensor has an integrated amplifier and is temperature compensated in the range of 0 to 50 °C.

The sensor is connected to the electronics with an individual plug connector.

A recalibration should be performed at least every second year (see chapter 12 Replacement parts and accessories).

#### 4.2.1.3 Carbon dioxide sensor

The used $CO_2$ probe is a single-beam infrared sensor for a range of 0 to 3 vol% (percent by volume). IR-$CO_2$ sensors utilize the absorption of infrared light at certain spectral ranges ($CO_2$ molecular pulsation). This makes them very stable and selective.

The $CO_2$ sensor is also connected to the electronics with an individual plug connector. The $CO_2$ -Sensor must always be connected to the electronics before turning on the system.

A recalibration should be performed once a year (see chapter 12 Replacement parts and accessories).

#### 4.2.1.4 Oxygen sensor

The oxygen is measured with a $ZrO_2$ sensor with a range of 0 … 25 vol%. The principle of this sensor is that, at a temperature of approx. 350 to 500 °C, $ZrO_2$ is

able to transport oxygen. The sensor must be heated and therefore, needs about 10 minutes for heating up and to reach full capacity.

Then, when a constant voltage is applied, the current will change in dependence of the volume percent of oxygen in the measured gas.

The oxygen sensor has a typical working life of at least 5 years and must not be recalibrated. A functional test would be to measure normal air where the measured value should be approx. 20,8 to 20,9 vol%.

**Never change the length of the oxygen sensor cable! This would change the heating voltage and the sensor calibration would be falsified.**

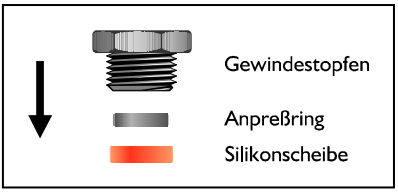
### 4.2.1.5 Septum

The Septum is integrated in the measuring head and consists of a silicone disc, a contact pressure ring and a holed thread plug.

Through the septum defined amounts of gas can be withdrawn or added, which is required for the headspace determination.

**The withdrawn gas sample might be used for further determination or for calibration if it is tested with an gas chromatograph Please observe that withdrawing gas from the system will reduce the system pressure.**

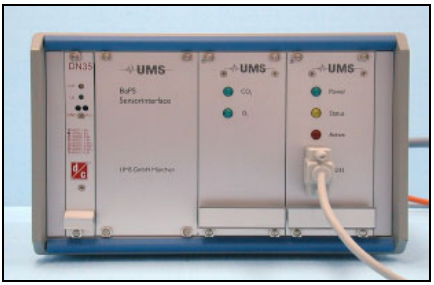
Please replace the septum regularly to assure the gas tightness of the system (after approx. 20 times of sampling). Push through a different spot on the disc each time.




Screw off the holed thread plug for replacing the septum. A metric size 17 fork wrench or adjustable wrench is required. Remove the silicone disc by pushing it out from the inside through the boring. Now, press in a new silicone disc, replace the contact pressure ring and tightly screw on the holed thread plug (see figure).

## 4.3 BaPS sensor interface unit

The job of the sensor interface unit is to convert the analogue sensor signals to digital signals and to communicate the computer.



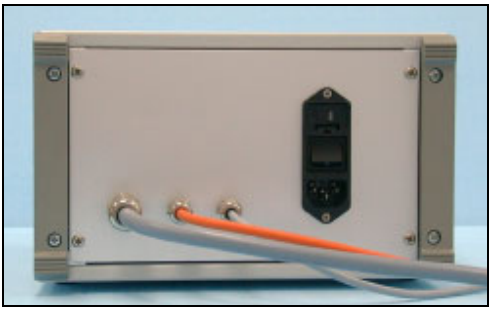

**For questions regarding the electronics of the sensor interface please contact Mr. Andreas Steins, graduate engineer, by e-mail (as@ums-muc.de) or telephone (+49 (0)89 - 12 66 52 - 18).**

The enclosure is a standardized plug-in rack for easy maintenance and removing of the components.

Use the proper mains power supply cable. The mains switch is on the backside of the enclosure. As soon as the interface is switched on, all connected sensors in the measuring head are supplied with power. When turned on, the diodes on the mains power supply and on the plug-in module are lightened.

A 230 Volt / max. 1 ampere quick-acting fuse is integrated in the mains power supply module. Find a supplied spare fuse in the fuse box. For replacement, disconnect the power cable first! Then, pull out the fuse box by pushing the snap cap upwards. Replace the fuse and push back the fuse box.

**Only expert electronic personal should open the enclosure. Before opening always disconnect the mains power supply cable first.**



The measuring head is linked to the interface unit with three cables which are inseparably connected to the interface enclosure. To prevent false connections each plug is of a different type. Connect all plugs to the measuring head before switching on the interface. This is required for initializing the sensors.

If required, it is possible to connect up to three more sensors. Please contact UMS if you need assistance.

There are three plug-in modules in the interface enclosure:

- The mains power supply module.
- The $CO_2$ and $O_2$ amplifier module.
- The BaPS electronics module.

Connect the supplied RS232 interface cable to the RS232 interface plug which located on the front side of the BaPS module. If your computer should only have one 25-pin RS232 interface plug an adapter is needed which is supplied by computer stores or could be ordered at UMS.

The BaPS interface unit may only be used in dry surroundings. Keep it away from any source of heat and do not expose the unit to direct sunlight during operation. Besides possible damage heating up will cause inaccuracies of the electronics.

### 4.3.1 Interface

The communication of BaPS software and BaPS interface is performed through a serial RS232 interface. Thus, the system is connectable to any IBM compatible computer.

Use the supplied data cable (Null modem cable), which can be connected in both directions.

TIP **Please observe that the appropriate COM port must be selected in the software (normally COM1 or COM2, refer to chapter 3.2 Find the COM port).** TIP

## 4.4 Syringe

With the syringe, a defined volume can be withdrawn from the headspace. This allows you to determine the headspace volume by measuring the pressure change. The headspace volume is required for the calculation of the conversion rates. Always used the calibrated syringe to achieve the lowest possible divergence from the specified volume (tolerance 1%).

Please use a proper hollow needle to prevent a destruction of the septum: "Luer-Lock" connector, stainless steel, outer diameter 0,5 mm, length minimum 20 mm.

Also, the syringe is needed at the end of each measurement. In general the process will cause a negative pressure inside the container. Then, to lift of the lid, some air must be added.

# 5 Software description

With the supplied BaPS software the user is able to adjust all set-ups and execute control and service routines.

The software will run under Windows® 95/98/ME, Windows® NT 4.0, Windows® 2000 and Windows® XP.

## 5.1 System requirements

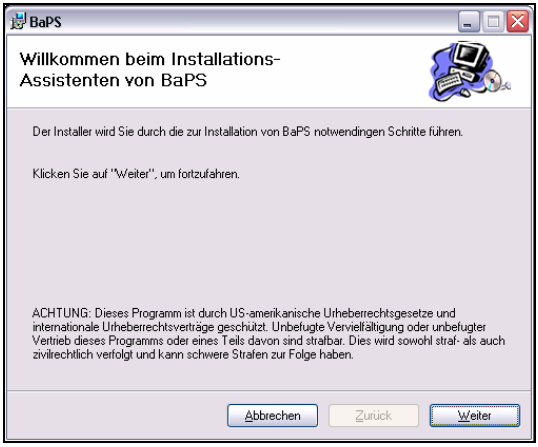
- Pentium 166 or higher (recommended)
- 32 MB RAM memory (recommended)
- 10 MB free hard-disc memory (necessary)
- Free RS232 interface (necessary)
- Graphic: 800 x 600, 65.536 colours (recommended)
- Mouse (necessary)

## 5.2 Installation

**In order to execute the installation properly, your system must use the comma as the decimal separator. Before starting the installation check or change your system settings (Regional settings in the Windows system set-up).**

The easiest way to install the software would be to call up the file "BaPS.msi“ directly from the CD, either with the Explorer or from your desktop. Select your CD drive and double-click on "BaPS.msi". Then, follow the instructions on the screen.

If you cannot execute the file "BaPS.msi" you might need a current version of the Windows Installer® by Microsoft. This program you will find on the BaPS-CD in the file directory "Windows Installer". Select your operating system, start the installation file and follow the instructions. After the successful installation continue to install the BaPS software as described above.


BaPS
Willkommen beim Installations-Assistenten von BaPS
Der Installer wird Sie durch die zur Installation von BaPS notwendingen Schritte führen.
Klicken Sie auf "Weiter", um fortzufahren.
ACHTUNG: Dieses Programm ist durch US-amerikanische Urheberrechtsgesetze und internationale Urheberrechtsverträge geschützt. Unbefugte Vervielfältigung oder unbefugter Vertrieb dieses Programms oder eines Teils davon sind strafbar. Dies wird sowohl straf- als auch zivilrechtlich verfolgt und kann schwere Strafen zur Folge haben.
Abbrechen
Zurück
Weiter

INFO **In case your system misses too many DLL's (Dynamic Link Libraries), the set-up program will install those DLL's first and then will require for a re-start of the PC. Re-start the PC first and then continue with the installation.** INFO

TIP **When installing the program to a Windows® NT, Windows® 2000 or Windows XP system, it might be necessary to have administrator rights. Please contact your system administrator in case of errors.** TIP

If you should not have a CD drive on your PC, please ask us for the installation program on floppy disk. Please note that the additional files listed in the following chapter are not included on the floppy disk due to too high storage requirements.

INFO **Call up the implemented online assistance by pressing the F1 button or through the Help menu (please read chapter 5.8 Online ).** INFO

**If you should need further assistance regarding the software, Mr. Thomas Pertassek, graduate engineer, would be pleased to support you. Please contact him by e-mail (tp@ums-muc.de) or phone (+49 (0)89 - 12 66 52 - 17).**

## 5.3 Additional files on the BaPS-CD

Besides the BaPS software the following files are added on the CD:

- This user manual in Acrobat Reader format (.pdf).
- An Excel® program including the calculation as executed by the BaPS software. Here you can follow the routine step by step and carry out changes.
- Photos of the BaPS system in jpg- und tif-format. Be free to use them for your publications.
- The current Acrobat Reader for viewing .pdf files.
- The Windows Installer for several operating systems.

## 5.4 Software structure

The program is divided into three different windows**Fehler! Textmarke nicht definiert.**. These windows reflect the different sections of BaPS measurements. Find a detailed description of each function in chapter 6 BaPS measurements.

### 5.4.1 The configuration window

In the configuration window all set-ups required for measurements are adjusted. For all parameters predetermined values are already set. These can be customised by the user depending on the needs of each measurement.

The following parameters can be adjusted:

- Required information regarding the measurement, as for example water content, sampling size etc.
- Starting terms when the measurement should start.

- Stopping terms when the measurement should stop.

Measurements are started from this window. Then, the measurement window will open automatically.

**TIP To carry out standard measurements previously defined and stored configurations can be reloaded (see chapter 6). TIP**

### 5.4.2 The measurement window

In this window all readings and the calculated conversion rates are displayed online. This offers the user the possibility to check the plausibility of the readings right away during a measurement.

The readings are displayed as a table and a graph. In case a stopping term is reached or the measurement is stopped manually, the evaluation window is opened automatically.

### 5.4.3 The evaluation window

When the measurement is completed the evaluation window opens and displays the calculated values. In this window the used reference points could be adjusted again as well a the preset parameter.

Whenever a completed measurement file is opened, the BaPS software will also automatically open the evaluation window. This offers the possibility to adjust a measurement even later (for example input of a different water content, dry weight, etc.).

If a measurement is not completed and the evaluation has not been executed, the program will ask if this measurement should be stopped. The evaluation will be possible in any case.

## 5.5 Data safety

When a measurement is started, all configuration values are instantly stored in the selected file. All readings during a running measurement are stored on the hard-disk as well. Then, the data will not be lost even if the PC is turned of or the system crashes.

**TIP** **Please always store a safety copy of your important measurement files on another data medium. This will prevent the complete loss of data by a failing hard disk.** **TIP**

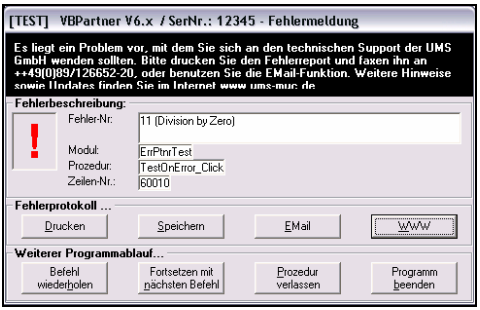
## 5.6 COM port settings

To communicate with the BaPS hardware the correct COM port must have been selected. To do this, click on "Properties" in the menu  and select the port where the hardware is connected to. The COM port might be searched automatically as well with the "Search" function (see chapter Find the COM port)

## 5.7 Error messages

A debug routine is integrated in the BaPS software. This will prevent a complete computer crash and will make quick fault analysis possible.

In case of a software error the following window will open:




There are three possible ways to keep a record of any errors and for sending them by email. You can either print out or save the protocol or send it directly to UMS. Select your preference by clicking on one of the following options:

Please always send the complete protocol to UMS to make it easier for us to trace the error. Also give us all information about the executed steps before the error occurred.

Then, there are four options on how to continue with the program.

If you will retry the procedure the error probably will occur again. You might try to continue by ignoring the error. In case of sequencing errors you should exit the procedure. In case of serious errors abort the complete BaPS program.

**Please always send the error that occurred first. Subsequence errors after ignoring the earliest error normally are not informative.**

**In case of program errors please contact Mr. Thomas Pertassek by e-mail (tp@ums-muc.de) or telephone (+49 (0)89 - 12 66 52 - 17).**

## 5.8 Online assistance

The integrated online assistance in PDF format can be viewed with the Adobe Acrobat Reader. Call the assistance files by pressing the F1 button on your keyboard or via the "Help" menu in the BaPS software.

If the Adobe Acrobat Reader should not be installed in your system download the set-up files from the "Acrobat Reader" directory on the BaPS software CD-ROM. To do so, read the "ReadMe" file for your OS in the "Acrobat Reader" directory and follow the installation instructions.

## 5.9 Info

Click on "Info“ in the "?" menu to view the software version and further system information.

Info zu BaPS
UMS
Version 0.9.3
BaPS
Barometrische Prozeß-Separation
© 2000 - UMS GmbH, Umweltanalytische Mess-Systeme
Warnung: UMS GmbH hat diese Software mit größter Sorgfalt und nach bestem Wissen erstellt. Für die richtige Funktion der Anwendung kann UMS GmbH trotzdem keine Gewähr übernehmen.
Copyright 2000 UMS GmbH München
OK
Systeminfo...

# 6 BaPS measurements

In this chapter the BaPS measurement including all possible options is described. The reader will get a comprehensive instruction on how to execute measurements.

## 6.1 Requirements for reliable measurements

- Sufficient temperature stability in headspace and soil.
- Gas- and water tight system.
- Sufficiently vented soil.
- Knowledge of the weight of the empty sampling rings to determine the weight of the soil samples themselves.

## 6.2 Taking and transportation of soil samples

**Bild *„BaPS Kammer mit Proben“***

After taking the soil samples they preferably should be transported in the incubation container closed with the transportation lid. Then, the samples are stored in the appropriate place right from the beginning.

Still, taking samples without the container is possible as well. Then, cover the soil sampling rings with the supplied rubber caps and place them in the BaPS container after they were brought to the laboratory.

### 6.2.1 Soil sampling

A main advantage of BaPS is the possibility to determine nearly undisturbed soil samples. To get the maximum out of this option the soil should be sampled with appropriate devices [HAR 1992].

We would be pleased to consult you about available soil sampling devices (see chapter 12 Replacement parts and accessoriesaccessories).

TIP **With loose soil the container might be flipped to the side. Then, the sampling rings can be inserted sideways and no soil will fall out.** TIP

Please always keep the O-ring seal and the sealing surface clean.

Carefully select the sampling site as this will characterise the whole measuring result. Write down the sampling site, date, soil temperature if possible, and soil moisture. All documented data will improve the evaluation.

If possible, weigh each soil sample right away before inserting it into the container. Consider the weight of the empty sampling rings (Tara). If you do not weigh the samples now, it still is necessary to weigh the samples before making measurements.

### 6.2.2 Transportation

To start a measurement as quick as possible, the container should be tempered to the required measuring temperature right from the beginning. For this the thermo-box is very helpful as it protects the samples and the container from heating up and from direct sunlight. If possible, pre-temper the container for example with cooling elements.

For transportation put the transportation lid onto the container and tighten the fly nuts. Screw down the nuts only slightly.

## 6.3 Assembling the sensor head

For measurements the transportation lid is replaced by the sensor head. Please make sure that the O-ring seal and the surface are clean and in good condition.

### 6.3.1 Installation of the soil temperature probe

Insert the temperature probe, in a slightly angular position, into the centre soil sample. Push in the probe so deep that the start of the green coating is at the same level as the top of the sampling rings.

**In no case the tip of the temperature probe may have contact with the Aluminium bottom of the container because then the cooling fluid would influence the measured temperature.**

Form a loop and place the cable over the cylinders. Be careful so the cable will not have contact with the fan.

### 6.3.2 Assembling the lid

The sensor head is closed with the fly nuts. In four steps screw down the nuts steadily and crosswise so the lid has a form-fit seat on the container. Fasten the nuts only hand-tight and do not apply force. This will assure a good thermal conduction between housing and lid. Also, internal or external pressure changes will not cause a change of the volume inside the container by compression of the O-ring.

### 6.3.3 Electronic connections

Connect the measuring head and the sensor interface with the three cables. There are three different plug sizes to prevent an accidental false polarity.

Please observe that the plug connections are only watertight (IP66) if they are completely screwed together. The 24-pin plug will even have IP68.

**Please always connect the $CO_2$ sensor first before switching on the interface so the sensor is initialized by the electronics. If the sensor is connected afterwards, the maximum reading of 3 vol% is displayed (as without an sensor) and no measurements are possible.**

## 6.4 Tempering the system

**To prevent condensation on the sensors by self-heating the measuring head must always be turned on before**

**starting the tempering of the container. The fan will circulate the air in the headspace to accelerate the temperature stableness.**

If you should not have a thermostat with external cooling, the closed container might be submerge into a water bath down to the starting of the 24-pin plug connector, but not deeper.

Much more accurate is the use of an thermostat with an external circuit and an active controller (see chapter Replacement parts and accessoriesaccessories). A cooling duct for tempering the container is integrated in the base of the chamber. The tubes for the tempering fluid are connected to the plastic quick-lock couplings.

Always temper with small gradients to allow an even temperature interchange within the container to reduce the chance of condensation as soil moisture will vaporise and condense on the inside of the measuring head.

One of the PT100 temperature probe is used for the thermostat regulation. The temperature output for connection to the thermostat is on the backside of the interface.

The thermostat should have the following specifications:

- External tempering circuit.
- Connector for an external temperature (PT1000, 4-wire measuring principle)
- PI or better PID controller
- Temperature range 0...50 °C

With an active thermostat regulation the typical time to reach a temperature stability of better than 0,2 °C would be one to two hours. Not until the temperature is stable the tightness test or measurements can be started.

## 6.5 Measurement set-up

Start the BaPS program by successively clicking "Start ⇐ Program ⇐ BaPS ⇐ BaPS". When the program is open, start a new measurement with "File ⇐ New Measurement".

Before starting a measurement some settings have to be entered. The window "Configuration – BaPS" will automatically open when you start a new measurement.

Alternatively previously saved configuration files may be reloaded. During the set-up, the momentary configuration can be saved at any time and with an individual file name for future use.

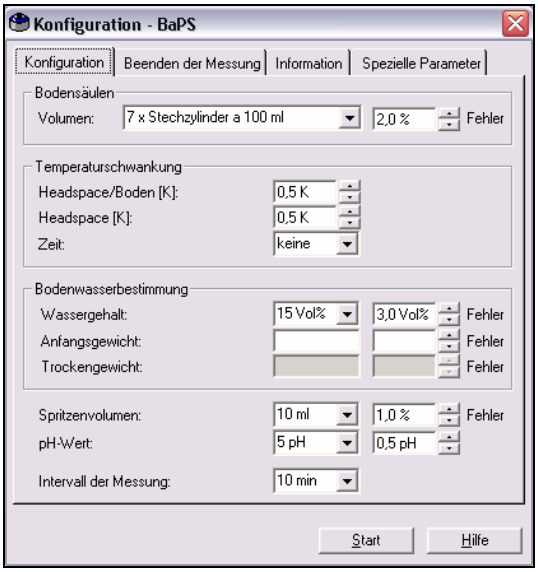
**TIP** **If you wish to reload the unsaved configuration of a previous measurement you can recall the stored measurement and then save the configuration afterwards.** **TIP**

An irregularly aborted previous measurement can be restarted with "File ⇐ Open measurement". The BaPS software will recognize that this measurement had not been terminated.

Some configuration settings require to enter an deviation limit. Plausible deviation tolerances are already preset (see chapter Error calculation). Tolerances which are crucial for the accuracy of the measuring results are called "critical deviations". Please do not change those values unless you are aware of the consequences for the error calculation.

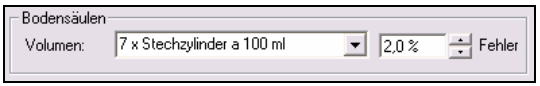
In general all settings may be entered manually by ignoring the preset values. The software will select the correct unit automatically. If the values are beyond the permitted limit the program will refuse them.

### 6.5.1 Configuration register




In this register all settings for the measurement and the evaluation are selected. For the correct error calculation it is essential to enter reasonable values. All settings have selectable default values.

### 6.5.1.1 Soil columns



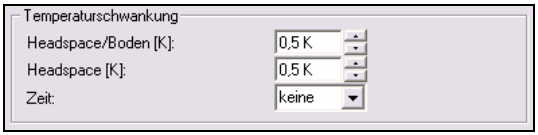

Select the total volume of the soil samples and the volume error in this section. These values are required for the evaluation of the rates.

Select one of the preset values for standard sampling rings or manually enter the total volume of all soil samples with the unit millilitres [ml].

If the rings are not completely filled manually enter the estimated total soil volume in millilitres.

Also, the error in percent [%] regarding the entered volume must be set. The value is uncritical for the evaluation if lower than 2%.

### 6.5.1.2 Temperature variations




The selected limits will be decisive for the moment when the measurement should start.

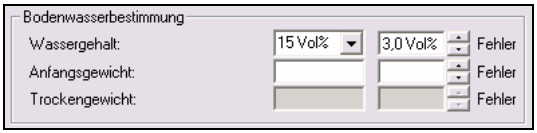
A sufficient temperature stability in headspace and soil is necessary for the implementation of a measurement. The temperatures are measured every minute. Within a period of 10 minutes the deviation of all 10 measured values must be within the selected limit. Thus, the start of a measurement will be delayed for at least 10 minutes unless it is started manually.

If a time limit is entered, the measurement always will start after the selected time period has passed. Also, the measurement can be started manually at any time.

Even when evaluating the readings afterwards the starting value can be changed to a later time. Therefore, preferably select a temperature variation limit which is rather to high than to low.

**INFO The temperature variation is controlled during a running measurement. If deviations larger than the selected limits occur, the program sends out a warning. INFO**

### 6.5.1.3 Soil water determination



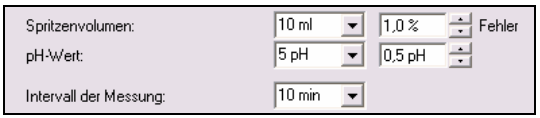
Enter the water content and the initial net weight (i. e. without sampling rings) of all samples before a measurement. The program will then calculate the dry weight of the samples.

To reach a better accuracy the dry weight should be determined with gravimetric methods after the end of the measurement. If you enter the dry value then, the water content will be recalculated automatically. All evaluations will then be executed with the new values.

For the later change of the dry weight value the measuring file must be opened.

**The parameters water content and dry weight are interdependent. If one value is changed manually the other value as well as it's error are recalculated. For evaluation, always the latest values are used.**

### 6.5.1.4 Further settings

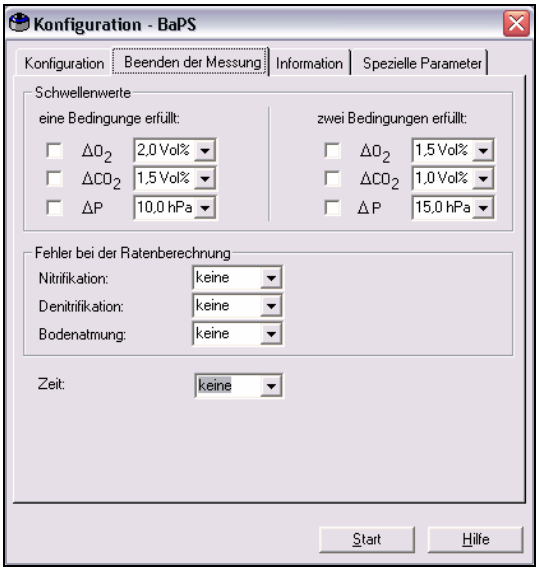



The volume of the syringe is required for the determination of the headspace. A 10 millilitre syringe is supplied as standard. The syringe should be calibrated and have a possibly low tolerance (typical 1%). As this tolerance is part of the headspace determination it influences the complete evaluation.

The pH value of the soil sample is required for the evaluation of the dissolved $CO_2$ in the soil solution.

Select in what intervals readings should be taken during the measurement. After each interval the termination values are verified. For a correct measurement only the starting and stopping terms are required. Still, to have a good signal stability and to control the quality of the measurement there should be at least 10 reading events within the measuring duration. The default value is 10 minutes.

## 6.5.2 Register Termination Conditions




In this register set the threshold values or the requirements for accuracy which will initiate the automatic termination of the measurement. If no termination conditions are selected, the measurement must be terminated manually. The default setting is manual termination.

**TIP** **Before a manual termination you can check the readings online to find out if the readings have changed sufficiently. For the evaluation of the conversion rates, any readings can be used.** **TIP**

In principle: The larger the changes in the starting and stopping readings are, the more accurate the measurement will be, as then the influence of the sensor inaccuracy is reduced. Therefore, measurements should not be terminated to

soon. If the system is not running to capacity, it is recommendable to extend the measurement and terminated manually.

With larger changes not only the results are improved but the measurement will take longer. How long will depend on type of soil, temperature, water and fertilizer content and other measures.

**INFO** **The error calculation depends on the measured gas changes and on the selected water content. Accordingly thresholds and accuracy are interdependent. The accuracy is improved when the dry weight is determined with gravimetric methods after the measurement.** **INFO**

### 6.5.2.1 Terminating values

For automatic termination the continuously measured changes in the $CO_2$, $O_2$ content and pressure can be used. Then, the program will terminate the procedure when, as selected, one or two adequate changes in one, two or three of the parameters occur. The program will always ask before finally terminating the procedure.

The possible terminating conditions are either only one of the selected condition is fulfilled (left column) or, at least two of the selected conditions are fulfilled (right column). If two conditions have to be fulfilled, the limiting values should be

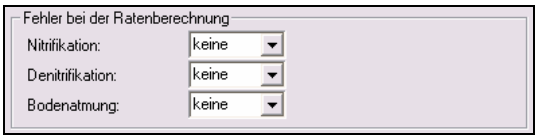
smaller. Tick on the parameter you wish to activate and select the limiting value. Not marked parameters a deactivated.

The limiting values must have a sufficient latitude to reach the required accuracy (see chapter error calculation).

**TIP** **To achieve a sufficient accuracy, the limiting values should be as or be higher than the following:** **TIP**

| | One condition fulfilled | Two conditions fulfilled |
|---|---|---|
| $O_2$ | 1 vol% | 0,7 vol% |
| $CO_2$ | 0,7 vol% | 0,5 vol% |
| Pressure | 5 hPa | 3 hPa |

### 6.5.2.2 Accuracy of the rate calculation



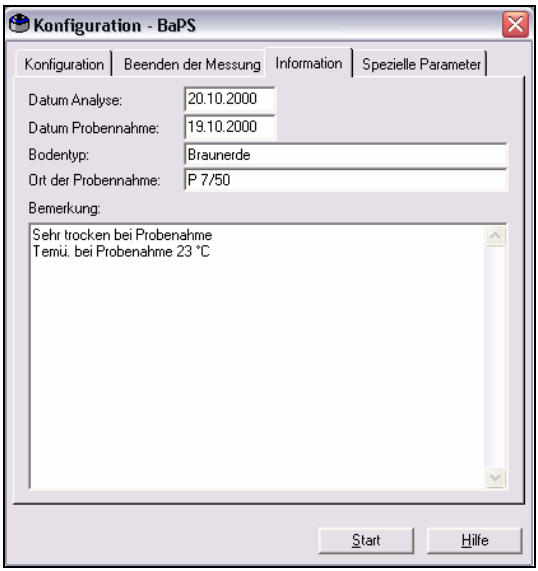

In addition to the terminating conditions the procedure could be terminated as soon as a sufficient accuracy in the rate calculation is achieved (see chapter error calculation). The measurement will be terminated if one of the conditions are fulfilled as selected. The achievable accuracy depending on your system and the type of soil should be known to select reasonable values.

The accuracy are entered as percentage [%] of the calculated rates.

**For calculating the accuracies, all entered error settings are assessed. Always have a plausibility check of the**

**settings before a measurement.**

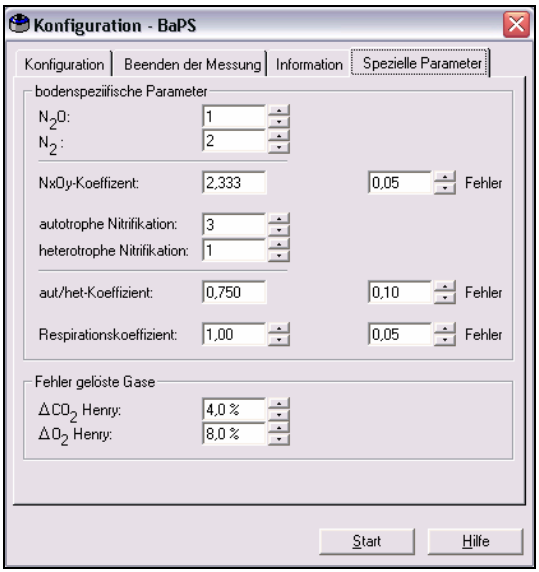
### 6.5.3 Information register



In the Information register you can enter details and specifications regarding the measurement. These are stored with the measurement file and can be recalled later.

The top input fields should be filled out. The comments field is to save any further information.

### 6.5.4 The Special Parameter register

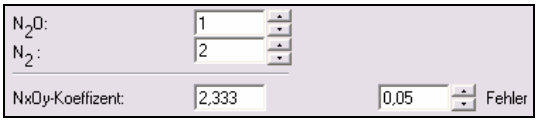


In this register the soil specific parameters and coefficients for the three processes are selected, as well as the errors for the calculation of the dissolved $O_2$ and $CO_2$.

The higher the relative share of a process to the total gas conversion is, the more crucial the selected values for this process are.

Select reasonable values for each error so the total error will not be falsified. Enter absolute errors that refer to the relevant coefficient.

### 6.5.4.1 NxOy coefficient



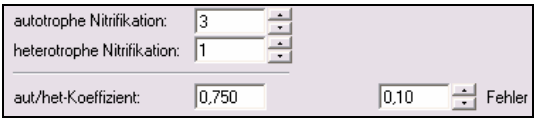

In this dialog the ratio of both final substances of denitrification, $N_2$ and $N_2O$, is selected. This information is required for the evaluation of the total gas balance because per 5 mol $CO_2$ either 2 mol $N_2$ or 2,5 mol $N_2O$ can develop (see chapter 9.1.3 Denitrification). The coefficient shows the mol-amount and therefore is between 2 and 2,5. The coefficient is calculated by the program regarding the selected ratio.

If the ratio is not known the preset coefficient of 2,3 should not be changed. This value is typical for soils.

TIP **For the ratio any value might be selected. For example a ratio of 1:2 is the same as 2:4 or 3:6. Rating a final substance as 100% should be avoided as this is not realistic for any processes.** TIP

The higher the denitrification rate is, the more important it is to know the ratio as accurate as possible..

### 6.5.4.2 aut/het coefficient

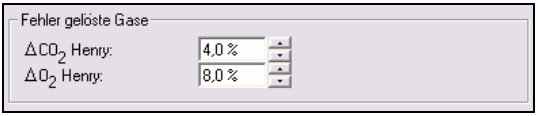



Select the ratio of autotrophic to heterotrophic nitrification in this fields. This information is required for the $CO_2$-balance, as autotrophic nitrifiers, contrary to heterotrophic, can bond $CO_2$.

Heterotrophic nitrification is predominant in acidic (persilicic) soils as forest soils, but autotrophic nitrification for example in arable soils.

Select the ration as for the NxOy coefficient. The automatically calculated aut/het coefficient is between 0 and 1. Then, 1 means 100% autotrophic nitrification, and 0 means 100% heterotrophic nitrification.

### 6.5.4.3 Error of dissolved gases




Here the error for the calculation of the dissolved gases can be adapted. As this is an added-up error it should only be modified if there is a essential reason (see chapter 9.1.12 Dissolved gases).

## 6.6 The measurement

After all settings in the configuration window are adjusted, the measurement is started. Call up "Measurement ➜ Start“ in the menu or click on the Start button in the configuration window

,

or on the start icon .

The measurement will start with the determination of the headspace.

### 6.6.1 Headspace determination and tightness test

First you are asked to determine the eadspace. Prepare the gas tight syringe (standard 10 millilitres). When you click on "OK " the software will take the first pressure reading.

Now prick the needle into the septum. Carefully withdraw exactly 10 ml (or the amount selected in the configuration) of gas out of the headspace, but do not pull out the needle. Wait for at least one minute to have a pressure equilibrium between BaPS and syringe. The pressure value is displayed online. When the

pressure is stable press "OK“ – now the second pressure value is measured. The headspace is calculated automatically from the difference of first and second pressure. Now remove the syringe.

TIP **If the difference of first and second pressure is larger than 0,1 hPa the waiting time after withdrawing gas was too short. The pressure was not stable and the headspace determination is falsified.** TIP

Afterwards the automatic tightness test is performed. (duration 10 min). You can skip the test by clicking on "Abort". The system is regarded as gas tight if the pressure does not arise for more then 0,2 hPa within 10 minutes. Only pressure increases are considered, as the processes inside the system normally will cause pressure decreases. The test is only functional if there is a pressure lower than atmosphere inside the container. This might not be the case if the system has been warmed up.

INFO **The tightness test after the headspace determination serves as the reference and helps to detect major leaks in the system. To assure a perfect function an additional tightness test should be performed every 3 to 6 months (see chapter ).** INFO

As soon as the program will request to do so, return 10 ml of gas into the container. Then click on “OK”. The window “BaPS measurement“ will open.

You are asked to enter a name for the measuring file. Please select an appropriate name an a directory of your choice. The file ending (.dat) should never be changed, because then the program will not be able to open this file again.

The measurement is started when the pre-set configuration parameters are reached. The first valid value is marked green in the table, invalid values are marked red. The first reading is always invalid.

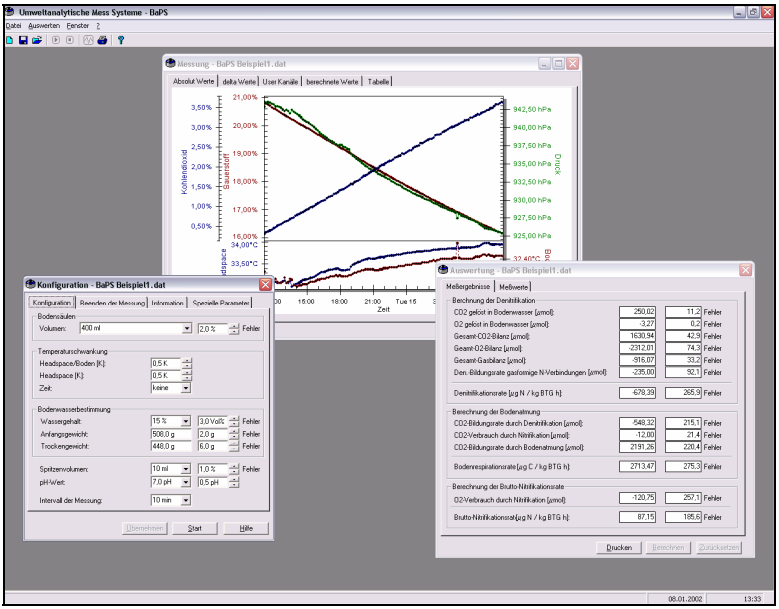
### 6.6.2 Automatic measurements

To test if the temperature stability is sufficient, 10 readings are taken minutely at first. These are not displayed. This means the next reading is displayed after 10 minutes.

During the measurement the readings are displayed graphical and tabulated. This readings are not the real sensor values but the temperature compensated values. From the pressure the water vapour is withdrawn. The gases dissolved in the soil are considered as well.

Thus, the factual evaluation of the conversion rates is possible even if for example the temperature is not constant.

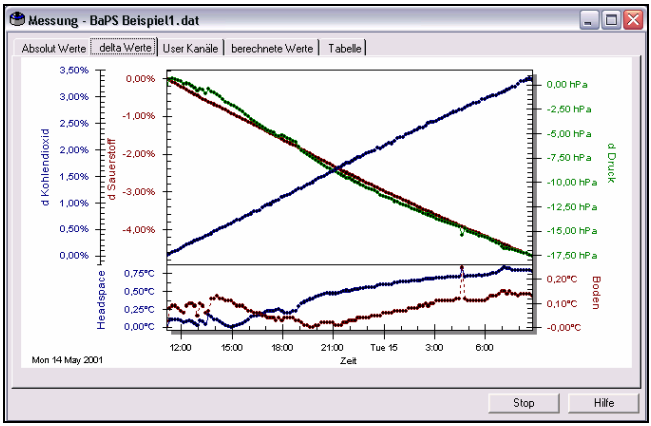
Graphical presentation




Select your own options for the intercept of the ordinate and the time gap in the graphical presentation. Click with the left mouse button on the unit axis for auto-scaling or formatting. The time axis can be zoomed by drawing over the requested time gap while the left mouse button is kept pressed. Click on the window with the right mouse button and select “undo zoom“ to cancel the zooming.

The absolute and the delta values (i. e. the changes of the values since the start of the measurement) are displayed in two separate registers. There, the continuing changes can be reviewed the best. The graphical presentation allows to recognise runaway values easily.

For displaying the absolute and the delta values not the raw sensor values are used but the $O_2$ and $CO_2$ dissolved in the soil water solution is calculated as well. Thus the factual changes of $O_2$, $CO_2$ and respectively the pressure are displayed more accurately.




The register „freier Sensor“ routinely is not needed but is used for an additional sensor.

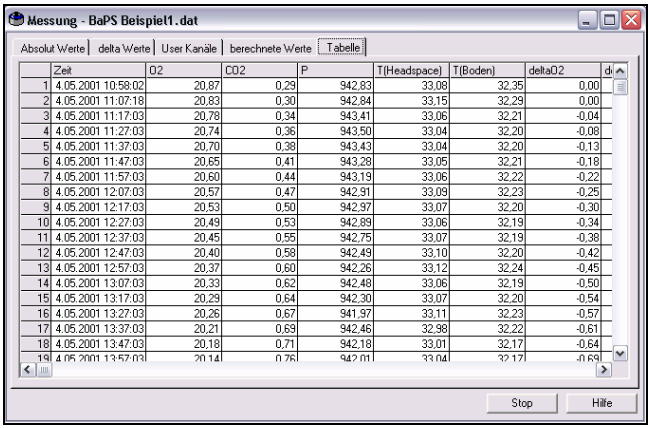
In the register „berechnete Werte“ the continuously calculated conversion rates are displayed graphical. Please bear in mind that these rates are based on partly temporary values (such as water content of the soil samples). Therefore, the rates will alternate distinctively in the beginning but will become more stable at the end.

**TIP Observing the stability might be a useful information when to terminate the measurement. TIP**

### 6.6.2.1 Presentation in tabular form

In the last register the values are displayed in a table. Move within the table by using the horizontal and vertical Bildlaufleiste.

During the measurement, valid values are marked green, invalid values are marked red.

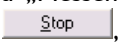



| | Zeit | O2 | CO2 | P | T(Headspace) | T(Boden) | deltaO2 |
|---|---|---|---|---|---|---|---|
| 1 | 4.05.2001 10:58:02 | 20,87 | 0,29 | 942,83 | 33,08 | 32,35 | 0,00 |
| 2 | 4.05.2001 11:07:18 | 20,83 | 0,30 | 942,84 | 33,15 | 32,29 | 0,00 |
| 3 | 4.05.2001 11:17:03 | 20,78 | 0,34 | 943,41 | 33,06 | 32,21 | -0,04 |
| 4 | 4.05.2001 11:27:03 | 20,74 | 0,36 | 943,50 | 33,04 | 32,20 | -0,08 |
| 5 | 4.05.2001 11:37:03 | 20,70 | 0,38 | 943,43 | 33,04 | 32,20 | -0,13 |
| 6 | 4.05.2001 11:47:03 | 20,65 | 0,41 | 943,28 | 33,05 | 32,21 | -0,18 |
| 7 | 4.05.2001 11:57:03 | 20,60 | 0,44 | 943,19 | 33,06 | 32,22 | -0,22 |
| 8 | 4.05.2001 12:07:03 | 20,57 | 0,47 | 942,91 | 33,09 | 32,23 | -0,25 |
| 9 | 4.05.2001 12:17:03 | 20,53 | 0,50 | 942,97 | 33,07 | 32,20 | -0,30 |
| 10 | 4.05.2001 12:27:03 | 20,49 | 0,53 | 942,89 | 33,06 | 32,19 | -0,34 |
| 11 | 4.05.2001 12:37:03 | 20,45 | 0,55 | 942,75 | 33,07 | 32,19 | -0,38 |
| 12 | 4.05.2001 12:47:03 | 20,40 | 0,58 | 942,49 | 33,10 | 32,20 | -0,42 |
| 13 | 4.05.2001 12:57:03 | 20,37 | 0,60 | 942,26 | 33,12 | 32,24 | -0,45 |
| 14 | 4.05.2001 13:07:03 | 20,33 | 0,62 | 942,48 | 33,06 | 32,19 | -0,50 |
| 15 | 4.05.2001 13:17:03 | 20,29 | 0,64 | 942,30 | 33,07 | 32,20 | -0,54 |
| 16 | 4.05.2001 13:27:03 | 20,26 | 0,67 | 941,97 | 33,11 | 32,23 | -0,57 |
| 17 | 4.05.2001 13:37:03 | 20,21 | 0,69 | 942,46 | 32,98 | 32,22 | -0,61 |
| 18 | 4.05.2001 13:47:03 | 20,18 | 0,71 | 942,18 | 33,01 | 32,17 | -0,64 |
| 19 | 4.05.2001 13:57:03 | 20,14 | 0,76 | 942,01 | 33,04 | 32,17 | -0,69 |

All values shown in the table are recorded in the measuring protocol.

### 6.6.3 Terminating the measurement

The measurement can be terminated manually when the data is regarded to be sufficient, or automatically when the pre-selected termination conditions are fulfilled.

For a manual termination follow the menu „Messen⇐ Beenden“, click on the button in the configuration window 

,

or click on the termination icon .

If termination conditions were activated the program will ask whether the measurement should be terminated after they have been fulfilled

The termination of the process must always be confirmed. This safety request should prevent an unwanted termination and give the user the possibility to verify the achieved data first.

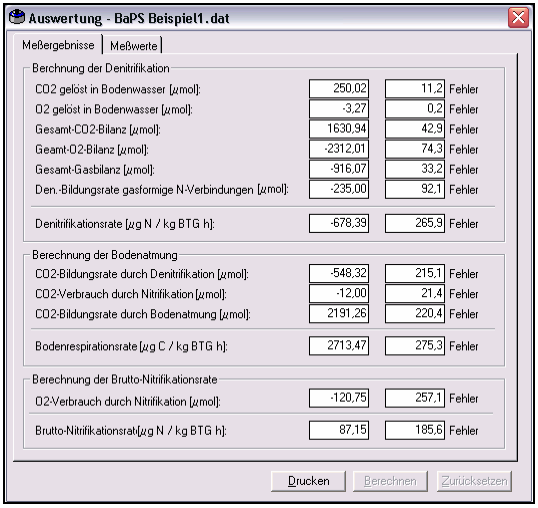
After the termination of the measurement the evaluation window is opened automatically.

In general, all data of the measurement or the configuration can be adapted afterwards. To do so just call up the measurement file. The affiliated configuration and measuring windows are then opened simultaneously.

**After the measurement you must always take of the sensor head to avoid condensation on the sensors. The sensor head and the incubation container should be stored in a dry place and without soil samples.**

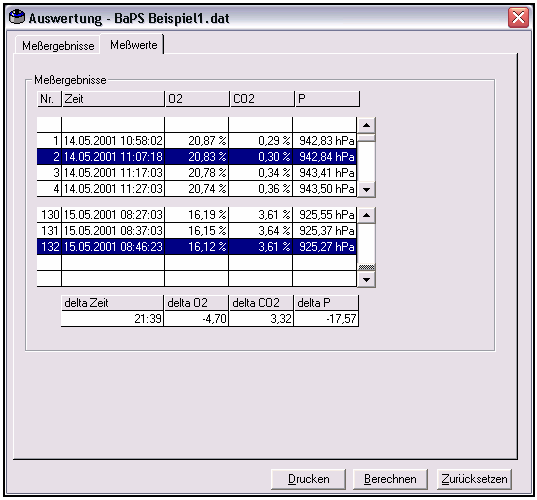
### 6.6.4 Evaluation window

In the evaluation window the calculation of the conversion rates can be retraced. Also the readings which should be used can be selected.


Auswertung - BaPS Beispiel1.dat
Meßergebnisse
Meßwerte
Berechnung der Denitrifikation
CO2 gelöst in Bodenwasser [µmol]: 250,02 11,2 Fehler
O2 gelöst in Bodenwasser [µmol]: -3,27 0,2 Fehler
Gesamt-CO2-Bilanz [µmol]: 1630,94 42,9 Fehler
Geamt-O2-Bilanz [µmol]: -2312,01 74,3 Fehler
Gesamt-Gasbilanz [µmol]: -916,07 33,2 Fehler
Den.-Bildungsrate gasformige N-Verbindungen [µmol]: -235,00 92,1 Fehler
Denitrifikationsrate [µg N / kg BTG h]: -678,39 265,9 Fehler
Berechnung der Bodenatmung
CO2-Bildungsrate durch Denitrifikation [µmol]: -548,32 215,1 Fehler
CO2-Verbrauch durch Nitrifikation [µmol]: -12,00 21,4 Fehler
CO2-Bildungsrate durch Bodenatmung [µmol]: 2191,26 220,4 Fehler
Bodenrespirationsrate [µg C / kg BTG h]: 2713,47 275,3 Fehler
Berechnung der Brutto-Nitrifikationsrate
O2-Verbrauch durch Nitrifikation [µmol]: -120,75 257,1 Fehler
Brutto-Nitrifikationsrat[µg N / kg BTG h]: 87,15 185,6 Fehler
Drucken
Berechnen
Zurücksetzen

The first and the last valid values are used as the default values.

In the register „Messwerte“ the readings used for the calculation can be selected with the scroll bars.




To execute the calculation of the conversion rates, press the "Berechnen" button. Now all data are update. With the "Zurücksetzen" button all settings can be undone.

## 6.7 Determination of the soil sample's water content

To increase the accuracy the water content should preferably be determined with a gravimetric method after the measurement.

The weight of the moist soil had been measured and set in the program in the beginning. Now, dry the soil samples in an drying chamber (24 hours at 105 °C) [HAR 1992]. When done, enter the dry soil weight in the window "BaPS – Configuration".

The calculation after clicking on "Calculate" is always complete with the current data.

## 6.8 Data documentation and processing

A main focus has been set on the documentation as well as on the processing of the data in other applications.

### 6.8.1 Measuring protocol

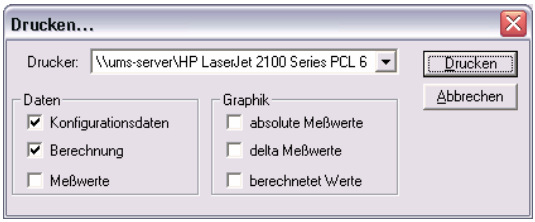
For every measurement the measuring protocol containing all significant data and results can be printed out directly via the BaPS software.

Start the print job by clicking on the "Print" button.

### 6.8.2 Printing results

Open the printer menu via the menu „Auswerten ➔Drucken“, or press the "Print" button Drucken in the window „Auswertung“,

or press the print icon in the task list .




In this menu the options for printing data or graphs can be set.

The following option are selectable:

Configuration data – prints all configuration data.

Calculation– Prints all results of the calculation.

Readings – Prints all readings including time stamp.

Absolute, delta, calculated readings –Prints the selected graph.

### 6.8.3 Exporting to other applications

For each measurement the BaPS software creates a measuring file which is stored with your selected file name.

**Please do not change any original measuring files as then the BaPS software will not be able to open these files again.**

In the measuring file all settings, readings and results are stored. The used format offers the possibility to export the data to other applications easily.

- ASCII format
- Separator: semicolon

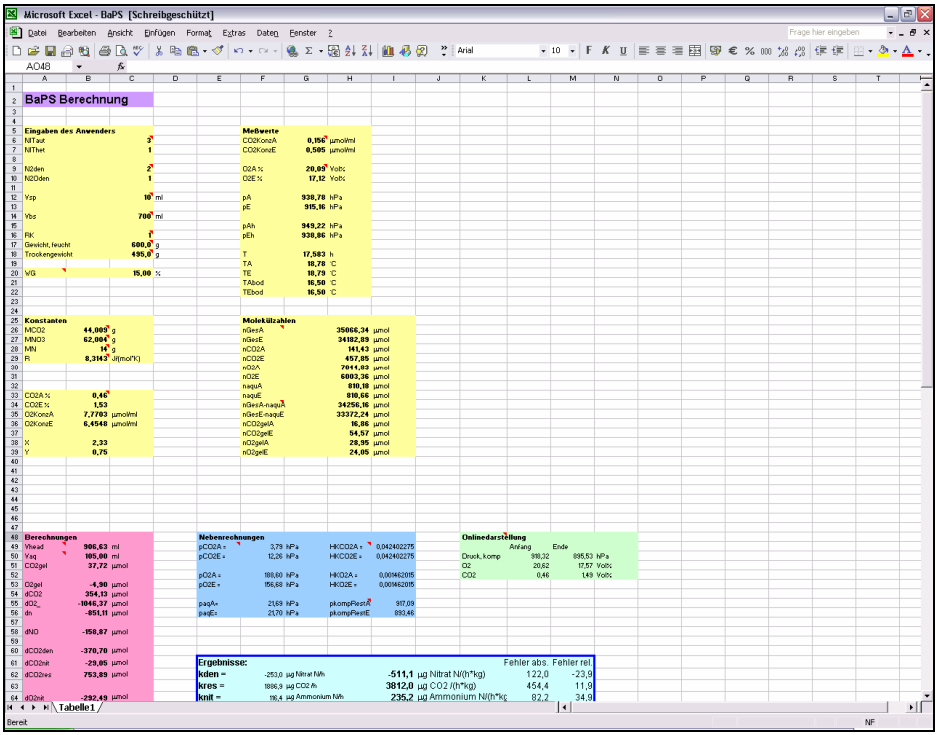
**Bodensäulen**
Volumen, Fehler,
Fläche, Fehler
**Temperaturschwankung**
Boden, Headspace, Zeit
**Bodenwasserbestimmung**
Wassergehalt, Fehler,
Bodengewicht feucht, Fehler,
Bodengewicht trocken, Fehler
**sonstige Parameter**
pH-Wert, Fehler,
Spritzenvolumen, Fehler,
Messintervall
**Schwellwerte**
eine Bedingung
O2, CO2, P,
Zwei Bedingungen
O2, CO2, P
**Standardabweichung**
Nitrifikation,
Denitrifikation,
Bodenatmung
**Zeit**
Abbruchzeit
**Spezielle Parameter**
$N_2O$, $N_2$, NxOy-Koeffizient, Fehler NxOy-Koeff.,
autotrophe Nitrifikation, heterotrophe Nitrifikation, aut/het-Koeffizient, Fehler aut/het-Koeffizient,
Respirationskoeffizient, Fehler Respirationskoeffizient,
Fehler $DCO_2$ Henry, Fehler $DO_2$ Henry

The configuration parameters are stored numerical. The values correspond to the parameters as followed:

Zero stands for not registered or not exciting values. In the following the readings are listed, followed by the results.

### 6.8.4 Calculations with Excel®

To recapitulate the calculations easily an Excel table is submitted. With the Excel® table each step of the calculation can be evaluated and adapted if required. The Excel® sheet is stored in the Excel directory of then BaPS software.



# 7 Maintenance and service

## 7.1 Cleaning the container

Clean the container only with pure water or in case of intense contamination with a cloth and Ethanol.

**The sensors in the sensor head may never get wet. Clean the inside of the sensor head only with a moist cloth.**

## 7.2 Tightness test

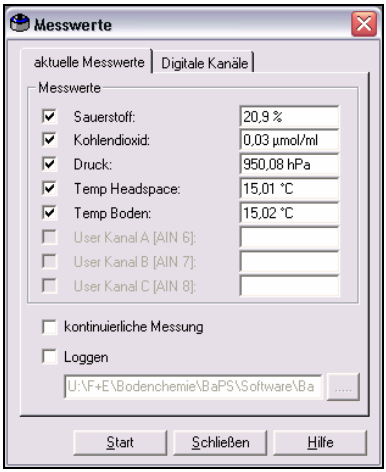
In addition to the 10 minute tightness test before every BaPS-measurement a thorough test can be executed to detect even smallest leaks (for example at the sensor gaskets). For testing gas is withdrawn from the empty container. Then, the pressure is observed for as long as possible. After the temperature compensation of the pressure value there should not be any changing in the pressure. The BaPS should be tempered during the test to keep temperature shifts small.

You may use the log-function in the window „aktuelle Messwerte“ (see chapter 7.3 Online sensor readings). With small temperature changes (< 0,1 °C) both measured pressure readings can be compared. The pressure increase should not be higher than 0,1 hPa per hour. If higher, the septum and all gaskets should be replaced (see chapter Replacement parts and accessories).

The additional tightness test should be executed every 3 to 6 months or whenever there are incidents that might indicate a leak or broken seal.

## 7.3 Online sensor readings

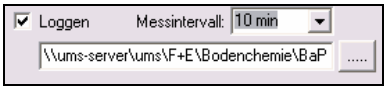
To check the sensors readings can be taken even if no BaPS measurement is running. Switch on the sensor interface and connect the sensor head with the computer. Then, press „Options ➜ current readings “ in the menu.




The measuring window is opened. Read the sensor data by pressing „Start“.

Please wait until the readings are updated before pressing „Start“ again. The readings can be updated continuously and automatically by selecting "Continuous measurement" in the register "aktuelle Messwerte" and by pressing the „Start" button. The continuous measurement can be stop by pressing the "Stop" button. The sensors which should be displayed can be selected with the tick boxes.

The readings can be written continuously in an ASCII file. To do so, select the option "Logging".




In the pull up menu adjust the measuring intervals and enter the file name and the directory. Operate the readings with the "Start“ and "Stop" button.

The used format in the log-file can easily be exported to other programs.

## 7.4 Calibrating the sensors

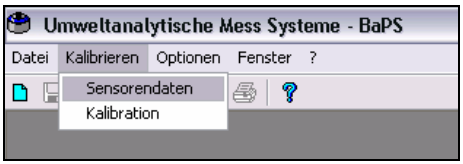
**Sensor calibrations should be executed annually by an engineering specialist. UMS offers the complete service for pressure, $O_2$- and $CO_2$ sensors as well as the recalibration and testing of the internal electronics (see chapter Replacement parts and accessories).**

### 7.4.1 Calibration parameters

With the calibration parameters the digital sensor specifications of the BaPS interface are adjusted to the physical units. Please change these parameters only if you have adequate knowledge of the correlations.

The calibration parameters for your BaPS are back-upped in a special txt-file. The parameters are taken over during the installation.

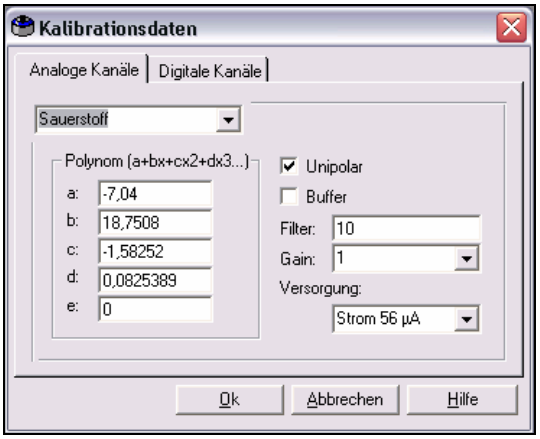
The sensor parameters can be viewed by calling up the menu "Calibration" ⇐ "Sensor specifications ".




#### 7.4.1.1 Polynomial conversion

The sensor readings are converted to physical values with the use of polynomials, maximum grade 4.

Enter the factors for each polynomial into the first column.




### 7.4.1.2 Further options

**Unipolar**

This describes the analogue input range. With the setting unipolar the analogue input range is up to 0 ... 2,5 V. If the setting is cancelled (empty tick box) the measuring then is bipolar with an input range of -2,5 ... 2,5 V.

**Buffer**

The buffer is an interim analogue amplifier. If this option is selected, the analogue direct impedance is increased. This is needed for connecting sensors with highly resistive signals.

If selected, the common-mode range changes from the normal (without buffer) -30 ... 3000 mV to +50 ... 3000 mV. With this the negative input cannot be connected to earth GND directly. When measuring for example resitances as PT100 an additional internal resistance must be inserted between Ain and GND in series.

**Filter**

Filter describes the smoothing. If this value is increased the measuring time is shortened, but this will cause that the variations of the readings increase. The value means the „first notch“ in Hz. Set it to a maximum of 50. This corresponds to a digital FIR filter.

**Gain**

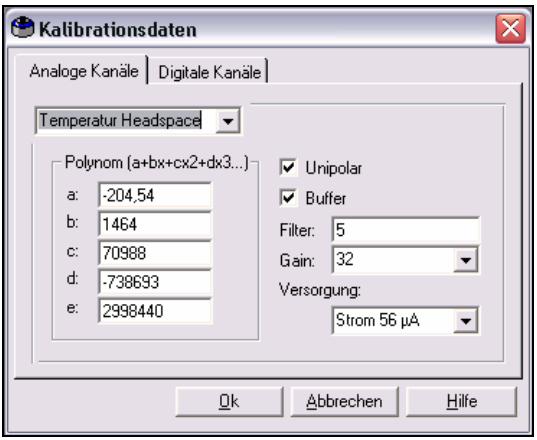
The gain is the internal amplification of the signal connected to the sensor interface. For standard sensors it must never be changed. A change of the gain will not change the signal as the software will re-calculate it. Still, with a too large gain the analogue measuring range is exceeded. A too small gain reduces the maximum resolution.

**INFO By selecting the buffer or by raising the gain the electronic performance might be reduced. INFO**

### 7.4.1.3 Temperature

PT1000 are used as temperature probes. They have a resistance of 1000 Ohms at 0°C and an increase of approx. 3,8 Ohm per °C. The sensors must be supplied with an constant current of approx. 56 µA. The voltage drop (approx. 215,6 µV/°C) is measured (see connection scheme for temperature sensor).

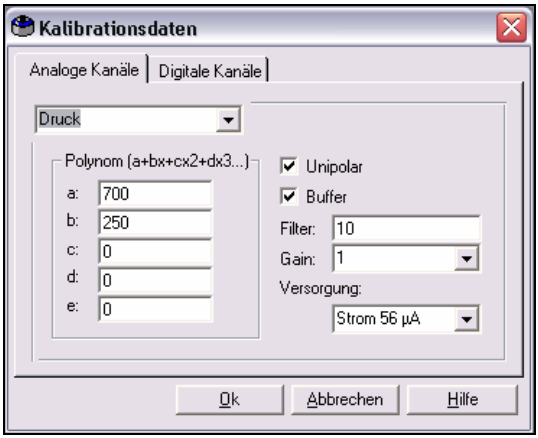
Find the optimum calibration data in the following figure.




In accordance to the small signal a larger gain is selected.

### 7.4.1.4 Pressure

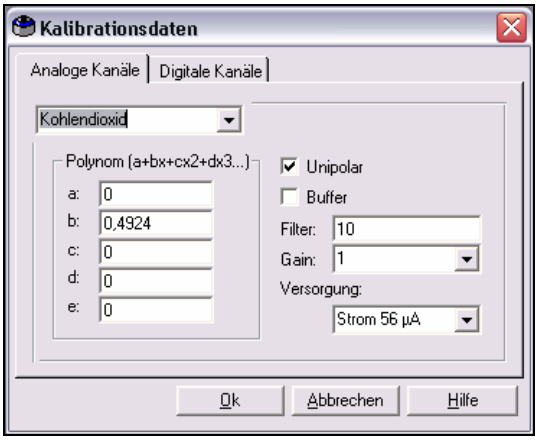
The pressure sensor offers a 4 ... 20 mA signal, the voltage drop on a 100 Ohm shunt resistance then is 400 ... 2000 mV for the range of 800 ... 1200 hPa. The best configuration is shown in the figure. With different pressure sensors the parameters might vary.




### 7.4.1.5 Carbon dioxide

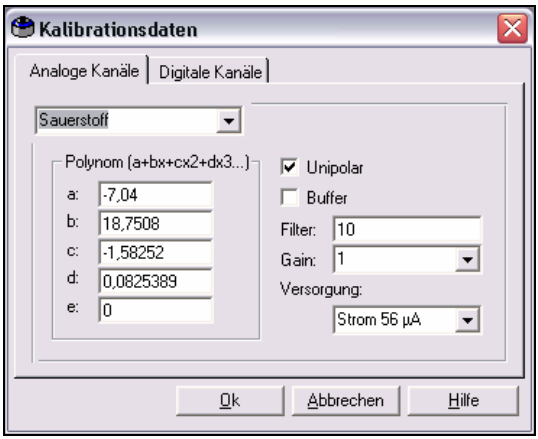
The $CO_2$ sensor offers a 0 ... 2,5 V signal for the range of 0...3 vol%.

Die optimum configuration is shown in the figure.

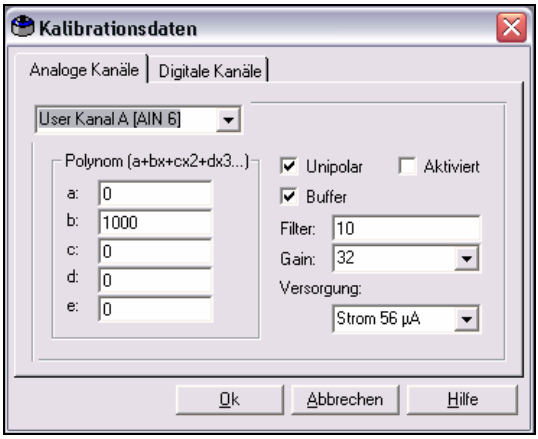



### 7.4.1.6 Oxygen

The $O_2$ sensor has a 4...20 mA signal which is not linear and specific for each individual sensor. Shown below is a typical configuration which might vary slightly from the one in your program.




### 7.4.1.7 User channel




Up to three additional sensors may be connected to the sensor interface (see chapter 4.3 BaPS sensor interface). The readings of these sensors can be recorded by the BaPS software as well. To do so, select the option "Activated" and adjust the calibration parameters to the physical units. To obtain a perfect performance please contact UMS for assistance.

**An improper connection of additional sensors might damage the sensor interface. Only trained specialist should do this. UMS offers an complete service.**

### 7.4.2 Digital channels

The digital channels are not used with the momentary version and therefore, are not described.

# 8 Theory of BaPS

## 8.1 Nitrification und denitrification in soils

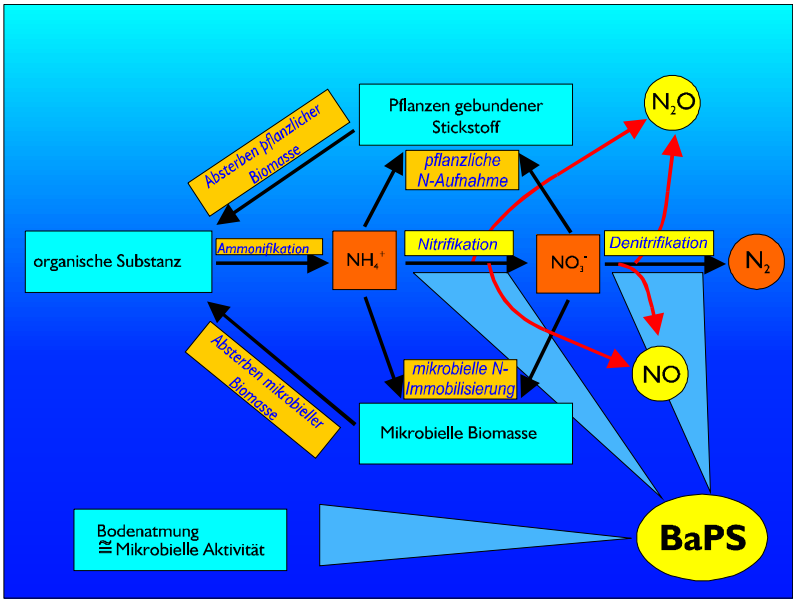



Figure: The nitrogen-cycle in terrestrial ecosystems and definition of the terms used in connection with N-conversion processes

Nitrification is the oxidation of ammonia [$NH_3$], in soils in an equilibrium with ammonium [$NH_4^+$], to nitrate [$NO_3^-$]. In the first step of this process, with hydroxylamin [$H_2NOH$] being developed, molecular oxygen is added to ammonia by the enzyme ammonia mono oxygenase. Another step of nitrification is the oxidation of hydroxylamin to nitrite [$NO_2^-$], which then is oxidised to the final product of the nitrification: nitrate.

Denitrification is the reduction of $NO_3$ under anaerobic conditions, with further reduced N-compounds succeeding and resulting in molecular Di-nitrogen [$N_2$] (nitrate → nitrite → NO → $N_2O$ → $N_2$).

### 8.1.1 Established measuring methods

Nitrification and denitrification are of major significance for the N-circulation in soils (see also fig.1). Still, nitrification is the process to focus on, as it is the most important stabilisation factor of the subsequent nitrate contribution and the only quantitatively important process of nitrate production in soils. Nevertheless, until now the $^{15}N$-pool dilution technique is the only method to determine **gross nitrification rates** in soils. This method is complex and needs an intense expenditure for tools and staff. The knowledge of the gross rates is absolutely necessary to make statements about actual conversion processes. When measuring the net rate no statement about the individual processes is possible..

### 8.1.2 $^{15}N$-pool dilution technique

With this method nitrate labelled with $^{15}N$-tracers is introduced to the soil. Then, the time dependent gradual dilution of the $^{15}N$-pool caused by the subsequent conversion of nitrate by nitrification is detected ($^{15}N$-pool dilution) [MOS 1993; DAV 1992]. The use of $^{15}N$ and its detection with a mass spectrometer makes this method very expensive (equipment costs, purchase of the marked substances, required replication of the tests, regenerating the samples). Besides, the following problems have to be considered:

1. The soil should be as homogenous as possible to achieve a symmetrical distribution of the marked nitrate. This would disturb the natural soil structure.
2. Adding $^{15}N$ tracers can cause a stimulation of the microbial decay processes. To avoid this problem it is recommended to terminate the $^{15}N$-tests within two days.

### 8.1.3 Determination of the net rate

Due to the high expenditure most investigations relating to N-cycles in soils actually do not determine the relevant gross nitrification rate, but simply the net

nitrification rate [ROW 1997]. The net nitrification describes the dynamics of changes of the nitrate pool in soils. Net nitrification is only an inadequate measure as it does not offer any conclusions about the gross nitrification (i.e. quantitative conversion of $NH_4^+$ to $NO_3^-$ by nitrification).

For a typical determination of net nitrification rates soil samples free of roots are taken from a measuring site (i.e. for one reason to exclude ammonium and nitrate reception by roots, but to keep up denitrification and microbial N -immobilisation activities). Then, the soil sample is buried in a bag and incubated, usually for more than a month. By measuring the $NO_3$ pool size at the beginning of the incubation and at the end of the incubation the net nitrification is calculated ($P_{NO3(t=0)} - P_{NO3(t=1)}$ = net nitrification related to the soil dry weight).

### 8.1.4 Inhibition techniques

Inhibition technologies are applied in connection with the development and emission in soils of primary [$N_2O$] and secondary [NO] N-trace gases, which are of climatic relevance and are formed during both nitrification as well as denitrification. The process responsible for the development of trace gases, i.e. nitrification or denitrification, is described.

The most frequently applied inhibitor is acetylene. In low concentration [10 Pa] acetylene restrains nitrification. By measuring the difference of the $N_2O$ and/or NO emission of a soil sample before and after inhibition, the quantitative contribution of nitrification and/or denitrification to this emission is determined.

This method has some disadvantages:

1. Individual groups of nitrifiers might be insensitive to the inhibitor.
2. Indecisive distribution of acetylene in the soil sample (incomplete inhibition).
3. Additional not recognised processes might contribute to the $N_2O$ and NO development and might be identified as denitrification.

For the quantification of denitrification in soils the acetylene inhibition method is used beside the $^{15}N$-technique. This method is based on the fact that the final enzyme of the denitrification conversion of nitrate to molecular nitrogen is restrained by 10 vol% acetylene. However, new investigations have shown that, in the presence of atmospheric oxygen with high concentrations of acetylene, NO combined with $O_2$ converts to $NO_2$, which afterwards will disproportion into

nitrate and nitrite. This step is not quantifiable. After this was revealed by Bollmann & Conrad [BOL] and McKenney & Drury (1997), this standard technique for the determination of the denitrification is not applied any longer.

## 8.2 BaPS

The method of Barometric Process Separation developed at the IFU is a completely different solution for the determination of the gross nitrification in soils. It offers the enormous benefit that neither a $^{15}N$ dilution nor gaseous inhibitors have to be introduced.

## 8.3 Detectable parameters

By recording changes in air pressure as well as the $O_2$ and $CO_2$ net balances within the closed, gas and pressure tight isothermal system containing intact well-aerated soil core, the Barometric Process Separation [ING 1999] allows to determine the following parameters:

- The current denitrification, nitrificationand and soil respiration rates.
- The dominating microbial process (denitrification and/or nitrification) in soils at a certain time.
- With consideration of supplementing investigations the rate of how much each process is involved in the observed $N_2O$ emission.

## 8.4 Description of the measuring method

In a gas and pressure tight system, in which a soil column is inserted, the following micro-biological processes are responsible for any changes of the system pressure: Soil respiration, nitrification and denitrification, and the dynamic equilibrium ($\Delta CO_{2aq}/\Delta t$) of the $CO_2$ concentration in the head space $CO_2(g)$ and the $CO_2$ concentration in the aqueous phase $CO_2(aq)$.

## 8.5 Individual processes

Soil respiration is neither a net gas producing nor consuming process, i.e. the net gas production $\Delta n/\Delta t = 0$, because the amounts of oxygen consumption and $CO_2$

production are identical, provided the respiration coefficient equals 1.0, as it is the case in well-aerated soils.

Nitrification causes a pressure decrease in the system, since 0.5 mol molecular oxygen per mol ammonium is consumed, but no gas is produced.

Denitrification however causes a pressure increase since no gas is consumed, but, beside $N_2$, an additional amount of 2.5 mol $CO_2$ is contributed during the complete reduction of 4 mol nitrate to 2 mol molecular di-oxygen.

## 8.6 Relevant equitation

If a net pressure decrease is observed, nitrification in the system is predominant. Therefore, a pressure increase indicates that denitrification is the dominating process. The three micro-biological processes can be described by the following reaction equations:

a) Soil respiration:

$$CH_2O + O_{2,Atm} \rightarrow CO_{2,Atm} + H_2O \text{ (pressure neutral)}$$

b) Nitrification:

$$NH_4^+ + 2O_{2,Nit} \rightarrow NO_3^- + H_2O + 2H^+ \text{ (pressure decrease)}$$

c) Denitrification:

$$5CH_2O + 4NO_3^- + 4H^+ \rightarrow 5CO_{2,Den} + 7H_2O + 2N_2$$

(pressure increase)

$CO_2$ and $O_2$ concentrations (optionally $N_2O$ concentrations) in the headspace over the soil samples are measured at the same time as the system pressure.

By measuring the system pressure changes the total gas balance $\Delta n/\Delta t$ [$\mu$mol $h^{-1}$] of the four processes can be determined.

By a combination of this gas balance with the $O_2$ and $CO_2$ balance, the rate of the gaseous nitrogen compounds $N_xO_y$ ($N_xO_y$ = $N_2$, $N_2O$, NO) contributed by denitrification can be determined.

If the total gas balance of the system, determined by the pressure measurement, is not explainable with the oxygen and $CO_2$ balance (total gas balance → oxygen balance plus $CO_2$ balance), this balance gap must be a result of the gaseous nitrogen compounds ($N_xO_y$) formed during denitrification.

Derive these correlation by the following differential equation:

$$\left(\frac{\Delta n}{\Delta t}\right) = \frac{\Delta p\, V_{BS}}{R\, T\, \Delta t} = \left(\frac{\Delta CO_2}{\Delta t}\right)_{Den} + \left(\frac{\Delta N_x O_y}{\Delta t}\right)_{Den} + \left(\frac{O_2}{\Delta t}\right)_{Nit} - \left(\frac{\Delta CO_2}{\Delta t}\right)_{aq}$$

$$\left(\frac{\Delta CO_2}{\Delta t}\right) = \frac{V_{BS}}{R\, T\, \Delta t}\left[p(x)[CO_2]_{=x} - p(0)[CO_2]_{=0}\right] = \left(\frac{\Delta CO_2}{\Delta t}\right)_{Den} + \left(\frac{\Delta CO_2}{\Delta t}\right)_{Res} - \left(\frac{\Delta CO_2}{\Delta t}\right)_{aq}$$

$$\left(\frac{\Delta O_2}{\Delta t}\right) = \frac{V_{BS}}{R\, T\, \Delta t}\left[p(x)[O_2]_{=x} - p(0)[O_2]_{=0}\right] = \left(\frac{\Delta O_2}{\Delta t}\right)_{Res} + \left(\frac{\Delta O_2}{\Delta t}\right)_{Nit}$$

with:

$V_{BS}$= gas reservoir of soil column [$cm^3$]

R= universal gas constant [$JK^{-1}\ mol^{-1}$] (R=8.314 $J\ K^{-1}\ mol^{-1}$)

T= temperature [K]

p(x)= air pressure at time t=x [Pa]

Indices: Den: denitrification; Nit: nitrification; Res: respiration; aq: aqueous phase

By gradual resolving and substituting the main equation is obtained:

$$\left(\frac{\Delta N_x O_y}{\Delta t}\right) = \left(\frac{\Delta n}{\Delta t}\right) - \left(\frac{\Delta CO_2}{\Delta t}\right) - \left(\frac{\Delta O_2}{\Delta t}\right)$$

Therefore, $N_xO_y$ [$\mu$mol $h^{-1}$] is the difference of the gas balance [ $\mu$mol $h^{-1}$], $CO_2$ balance [$\mu$mol $h^{-1}$] and $O_2$ balance [$\mu$mol $h^{-1}$]. With an inverse balance soil respiration and nitrification can be quantified:

# 9 Calculus

## 9.1 Description of the applied algorithms

In general all readings are temperature compensated.

### 9.1.1 Basic equation

The basis for measuring the nitrogen and carbon dioxide conversion rates are the following three equations. Noted below are not the complete chemical equations but only those segments which are gaseous or contain N or C.

Soil respiration

$$O_2 \rightarrow RK \cdot CO_2$$

Nitrification

$$Y \cdot CO_2 + 7{,}3 \cdot O_2 \rightarrow 3{,}65 \cdot NO_3$$

Denitrification

$$2 \cdot NO_3 \rightarrow X \cdot CO_2 + [NO \text{ oder } N_2O \text{ oder } N_2]$$

Here the respiratory coefficient RK is approx. 1, Y is between 0 and 1, and X between 2 and 2,5.

### 9.1.2 Calculating the gas conversion rates

#### 9.1.2.1 Headspace volume

By means of the ideal gas law pV = nRT the headspace volume is calculated from the increase of the volume by the syringe volume:

$$V_{head} = \frac{V_{sp} \cdot p_{Eh}}{p_{Ah} - p_{Eh}}$$

### 9.1.2.2 Water volume

The water volume can either be determined by using the water content and the soil sample volume:

$$V_{aq} = \frac{V_{bs} \cdot WG}{100}$$

or with the mass of the contained water:

$$M_{aq} = M_{Bod,f} - M_{Bod,t}$$

whereat

$$V_{aq} = M_{aq}$$

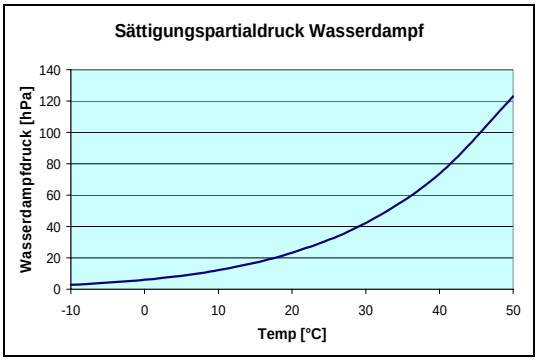
with $V_{aq}$ in ml and $M_{aq}$ in g.

### 9.1.2.3 Saturated vapour pressure

As a consequence of the water content in the soil samples there is always a relative air moisture of 100% in the closed BaPS container. This partial pressure changes with the temperature as the saturated vapour pressure is very temperature-dependent. This pressure difference caused by temperature variations between the start and the end of a measurement must be obeyed additionally to the changes calculated from the ideal gas law.

Table of the saturation partial pressure by [LIL1984]

| Temp. [°C] | -10 | 0 | 10 | 20 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|
| $P_{aq}$ [hPa] | 2,85 | 6,11 | 12,3 | 23,4 | 42,4 | 73,7 | 23 |




The saturated vapour pressure is shown in the figure. The curve is approximated by the following polynomial:

$$p_{aq} = 5{,}295 \cdot 10^{-6} \cdot T^4 + 2.003 \cdot 10^{-4} \cdot T^3 + 1{,}444 \cdot 10^{-2} \cdot T^2 + 0{,}4536 \cdot T + 6{,}093$$

For the calculation this portion is withdrawn from the total pressure. The calculation is continued with the portion of "dry" air.

### 9.1.2.4 Dissolved carbon dioxide

To receive the total balance of $CO_2$ the portion dissolved in the soil water is needed. Then, the portion in the beginning of the measurement is withdrawn from the portion in the end.

Decisive for the amount of gas dissolved in water always are the partial pressure and the temperature.

The partial pressure is obtained from the concentration by:

$$p_{CO_2} = CO_{2,konz} \cdot R \cdot (T + 273{,}15)/100$$

The temperature dependence is calculated with empirically determined Henry constant. BaPS uses the following approximate polynomial:

$$HK_{CO_2} = 3{,}09905 \cdot 10^{-5} \cdot (T + 273{,}15)^2 - 0{,}01931(T + 273{,}15) + 3{,}03553$$

The portion of additionally dissolved $CO_2$ is calculated as:

$$CO_{2,gel} = V_{aq} \cdot \left(HK_{CO_2}(t_2) \cdot p_{CO_2}(t_2) - HK_{CO_2}(t_1) \cdot p_{CO_2}(t_1)\right)$$

### 9.1.2.5 Dissolved oxygen

The partial pressure of $O_2$ is obtained from the vol% by:

$$p_{O_2} = Vol\%_{O_2} \cdot p/100$$

With the Henry constant for $O_2$:

$$HK_{O_2} = 6{,}9509 \cdot 10^{-7} \cdot (T + 273{,}15)^2 - 4{,}3304 \cdot 10^{-4} \cdot (T + 273{,}15) + 6{,}8576 \cdot 10^{-2}$$

the result for dissolved $O_2$ is:

$$CO_{2,gel} = V_{aq} \cdot (HK_{CO_2}(t_2) \cdot p_{CO_2}(t_2) - HK_{CO_2}(t_1) \cdot p_{CO_2}(t_1))$$

The amount of dissolved $O_2$ is significantly lower than the amount of $CO_2$. As the oxygen partial pressure normally decreases during a BaPS measurement the result for $O_{2,gel}$ usually is negative.

### 9.1.2.6 Gas concentration

Essential for the calculation of the conversion rates are the gas concentrations. For $O_2$ they are determined from the vol% value and the pressure.

$$Konz = \frac{Vol\% \cdot p}{R \cdot (T + 273{,}15)}$$

The $CO_2$ sensor directly measures the concentration.

### 9.1.2.7 Gas conversion rates

The $CO_2$ conversion rate is calculated from the concentrations at the beginning and at the end of the measurement and from the portion of $CO_2$ additionally dissolved in the soil water.

$$dCO_2 = V_{head}(Konz_{CO_2}(t_2) - Konz_{CO_2}(t_1)) + CO_{2,gel}$$

The $O_2$ conversion rate is calculated accordingly:

$$dO_2 = V_{head}(Konz_{O_2}(t_2) - Konz_{O_2}(t_1)) + O_{2,gel}$$

The total gas conversion rate which is reflected by the pressure change in the system is calculated as:

$$dn = \frac{100 \cdot V_{head}}{R} \cdot \left( \frac{p(t_2)}{T(t_2) + 273{,}15} - \frac{p(t_1)}{T(t_1) + 273{,}15} \right) + CO_{2,gel} + O_{2,gel}$$

whereat the pressure is the total pressure minus the vapour pressure.

### 9.1.3 Denitrification

In the first step the denitrification is calculated. Thus, the effect is used that the surplus of the total gas conversion rate only depends on the nitrogen compounds which are produced by denitrification. Then, the $CO_2$ and the $O_2$ portion are withdrawn from the total rate.

$$dNO = dn - dCO_2 - dO_2$$

As a direct result of this rate obtain the denitrification rate by:

$$k_{Den} = 2 \cdot \frac{dNO \cdot M_N}{(t_2 - t_1) \cdot M_{Bod,t}}$$

### 9.1.4 Soil respiration

The calculation of the soil respiration rate now is possible by using the $CO_2$ balance.

It must be considered that $CO_2$ is produced during denitrification, and $CO_2$ is consumed by the autotrophic nitrification.

With denitrification the amount of the developed $CO_2$ molecules depends on the end product.

- For $N_2$ as end product 2,5 $CO_2$ molecules are developed.
- For $N_2O$ as end product 2 $CO_2$ molecules are developed.

The $CO_2$ balance of the denitrification is calculated as:

$$dCO_{2,den} = X \cdot dNO$$

whereat the factor X is obtained from:

$$X = 2{,}5 \cdot \frac{N_{2,den}}{N_{2,den} + N_2O_{den}} + 2 \frac{N_2O_{den}}{N_{2,den} + N_2O_{den}}$$

With autotrophic nitrification besides $O_2$ also $CO_2$ is bound. The stoichiometric ratio is shown by the following equation:

$$NH_3 + 1.68O_2 + 0{,}23CO_2 \rightarrow 0{,}05C_5H_7O_2N + 0{,}86H_2O + 0{,}95HNO_3$$

The ratio of $O_2$ to $CO_2$ at nitrification for a purely autotrophic case then is:

$$dO_{2,nit} = 7{,}3dCO_{2,nit}$$

Thus, the $CO_2$ consumption of the autotrophic nitrification can be calculated. The base for this is:

1. The soil respiration does not contribute to the total gas balance as the amount of consumed $O_2$ is equal to the amount of produced $CO_2$ (This is only valid for a respiration coefficient of 1).
2. The ratio between autotrophic and heterotrophic nitrification is known.

Then the portion of $CO_2$ consumed during the nitrification can be calculated by withdrawing the portion of the denitrification:

$$dCO_{2,nit} = Y \cdot \frac{1}{8{,}3} \cdot \left(dn - dCO_{2,den} - dNO\right)$$

with

$$Y = \frac{NIT_{aut}}{NIT_{aut} + NIT_{het}}$$

With this the calculation of the $CO_2$ conversion by soil respiration is possible:

$$dCO_{2,res} = dCO_2 - dCO_{2,nit} - dCO_{2,den}$$

The soil respiration rate then is:

$$k_{res} = dCO_{2,res} \cdot \frac{M_{CO_2}}{(t_2 - t_1) \cdot M_{Bod,t}}$$

### 9.1.5 Nitrification rate

For calculating the nitrification rate the oxygen conversion of the nitrification is required. Therefore, the oxygen conversion rate of the soil respiration has to be determined first:

$$dCO_{2,res} = -RK \cdot dO_{2,res}$$

The oxygen conversion of the nitrification then is:

$$dO_{2,nit} = dO_2 - \frac{dCO_{2,res}}{RK}$$

and the nitrification rate:

$$k_{nit} = -\frac{1}{2} \cdot dO_{2,nit} \cdot \frac{M_N}{(t_2 - t_1) \cdot M_{Bod,t}}$$

### 9.1.6 Abbreviations used in formulas

#### 9.1.6.1 Index of variables

| | | | | |
|---|---|---|---|---|
| $CO_{2,gel}$ | | mmol | | $CO_2$ additionally dissolved in water (between start and end of measurement) |
| $dCO_2$ | | mmol | | Total $CO_2$ conversion rate |
| $dCO_{2,den}$ | | | | $CO_2$ conversion by denitrification |
| $dCO_{2,nit}$ | | | | = $CO_2$ conversion by nitrification |
| $dCO_{2,res}$ | | | | $CO_2$ conversion by soil respiration |
| dn | | mmol | | Total gas conversion rate |
| dNO | | mmol | | Conversion rate of gaseous nitrogen compounds during denitrification ($N_2$, $N_2O$, NO) |
| $dCO_{2,nit}$ | | | | $CO_2$ conversion by nitrification |
| $dCO_{2,res}$ | | | | $CO_2$ conversion by soil respiration |
| dn | | mmol | | Total gas conversion rate |
| dNO | | Mmol | | Conversion rate of gaseous nitrogen compounds during denitrification ($N_2$, $N_2O$, NO) |
| $dO_2$ | | mmol | | Total Oxygen conversion rate |
| $dO_{2,nit}$ | | mmol | | Oxygen conversion rate during nitrification |

| | | | | |
|---|---|---|---|---|
| $dO_{2,res}$ | | mmol | | Oxygen conversion rate during soil respiration |
| $dp_{Ah}$ | | hPa | | Pressure change at beginning of headspace determination |
| $dp_{Eh}$ | | hPa | | Pressure change at end of headspace determination |
| $HK_{CO2}$ | | | | Henry constant for $CO_2$ |
| $HK_{O2}$ | | | | Henry constant for $O_2$ |
| $k_{den}$ | | mg Nitrat-N / h | | Denitrification rate |
| $k_{nit}$ | | mg Ammonium-N / h | | Nitrification rate |
| $k_{res}$ | | mg $CO_2$ / h | | Soil respiration rate |
| $Konz_{CO2}$ | | mmol/ml | | $CO_2$ concentration |
| $Konz_{O2}$ | | mmol/ml | | $O_2$ concentration |
| $N_{2,den}$ | | | | Input of the user: amount of developed $N_2$ compared to $N_2O$ |
| $N_2O_{den}$ | | | | Input of the user: amount of developed $N_2O$ compared to $N_2$ |
| $NIT_{aut}$ | | | | Input of the user: ratio of autotrophic nitrification compared to heterotrophic nitrification |
| $NIT_{het}$ | | | | Input of the user: ratio of heterotrophic nitrification compared to autotrophic nitrification |
| $O_{2,gel}$ | | mmol | | $O_2$ dissolved in water (between start and end of measurement) |
| PCO2 | | hPa | | Partial pressure $CO_2$ |
| PO2 | | hPa | | Partial pressure $O_2$ |
| RK | | | | Respirator coefficient $O_2/CO_2$ during soil respiration |
| $V_{aq}$ | | ml | | Water volume |
| $V_{bs}$ | | ml | | Soil samples volume |
| $V_{head}$ | | ml | | Headspace volume |
| $V_{sp}$ | | ml | | Syringe volume |
| WG | | % | | Water content |
| X | | | | Factor: amount of $CO_2$ developed during denitrification compared to NO gases |
| Y | | | | Factor: amount of $CO_2$ degraded during nitrification (compared to $O_2$) |

### 9.1.6.2 Readings

| | | |
|---|---|---|
| $vol\%_{CO2}$ | vol% | $CO_2$ volume percent |

| | | |
|---|---|---|
| $vol\%_{O2}$ | vol% | $O_2$ volume percent |
| p | hPa | Pressure |
| $P_{Ah}$ | hPa | Initial pressure at headspace determination |
| $P_{Eh}$ | hPa | Final pressure at headspace determination |
| t | H | Time |
| $T(t_1)$ | °C | Temperature at beginning of measurement |
| $T(t_2)$ | °C | Temperature at end of measurement |
| $M_{Bod}$ | g | Weight of soil samples |

#### 9.1.6.3 Constants

| | | |
|---|---|---|
| $M_{CO2}$ | g | Mol weight of $CO_2$ (44,009g) |
| $M_N$ | g | Mol weight of nitrogen (14g) |
| R | J/(K*mol) | molar gas constant (8,3143 J/(K*mol)) |

### 9.1.7 Error calculus

In all calculations regarding BaPS certain principle uncertainties occur, which are unavoidable. These are among others for example the respirator coefficient = 1, the quantity of the ratio between $N_2$ to $N_2O$ during denitrification, or additionally developing gases (i. e. further processes appear). Therefore, in any case the final results should be verified if they are conclusive.

#### 9.1.7.1 Sensor errors

Measured parameters (sensors) generally have errors.

The following errors are significant:

- Linearity distortion, i. e. readings differ from the calibrated incline.
- Long term shifts in the sensor characteristic.

Sensor stability during the measuring time (offset drift). This error enters the final result absolutely.

- Noise: fluctuations of the sensors and the electronics determine the resolution, which means the maximal achievable accuracy. Noise errors can be reduced by proper electronic and digital filters.

- Additionally also the absolute values of the parameters are part of the measurement as the total number of molecules are determined. Errors of these parameters enter the calculations as linear errors. The long term shift is relevant as well. The required accuracy then is decisive for the calibration intervals.

### 9.1.7.2 Pressure

Typically pressure change of 3...10 hPa are measured. The highest achievable accuracy is 0,05 to 0,1 hPa . Then, the relative error is approx. 2 % of the pressure change.

When the headspace is determined pressure changes of approx. 10 hPa appear. The achievable accuracy is approx. 0,3...0,5%.

The typical long term shift in a year (absolute accuracy) is better than 0,5%. The sensors are calibrated to absolute 2 hPa when supplied.

### 9.1.7.3 Temperature

The absolute temperature can be measured as close as approx. 0,15 to 0,2K. Temperature changes are measurable down to 0,03 °C.

This parameter is very significant, as the other readings are compensated to the temperature. For example, a temperature change of 1 K will cause a pressure change of 3,6 hPa inside the system. Therefore, the accuracy of the temperature is crucial for the accuracy of the complete system.

An inappropriate temperature stability in the system will cause variable temperature gradients. Thus, a good temperature stability is essential.

### 9.1.7.4 Oxygen

Typically decreases of 1...2 vol% at approx. 20 vol% are measured.

The achievable accuracy over 10 hours is approx. 0,03 vol%, the stability over 3 years approx. 1% of the measuring range.

➜ the relative accuracy during a measurement is approx. 2%.

#### 9.1.7.5 Carbon dioxide

A change of typ. 1 vol% is measured in the range of 0...2 vol%.

The used sensor is a infra-red absorption probe.

The attainable accuracy over 10 hours is approx. ±0,02 vol%, the long term stability over 2 years approx. 3% of the measuring range.

### 9.1.8 Further error sources

Errors during the time measurement are neglectable small as time enters the rate calculation only linear.

#### 9.1.8.1 Measuring technique

1. During the determination of the headspace there is the error of the withdrawn volume. With precision syringes the error can be kept below 1%.
2. Temperature changes affect the pressure measurement (total gas amount). A temperature change of 0,1 K causes a pressure change of 0,36 hPa (at1000 hPa and 20 °C). Therefore, relative temperature changes have to be measured and compensated. This is possible with approx. 0,1 hPa.
3. Determination of the absolute soil water content: estimated values typically have an error of 3 ... 5% water content. Measurements with gravimetric methods are precise as min. 0,1%. Thus, it must be considered that depending on the type of soil (ultrapores) not always the whole water takes part in the chemical processes as the $CO_2$ replacement. Also, the partial pressure might be higher at the bottom than the partial pressure in the headspace.

#### 9.1.8.2 Systematic error

1. Soil samples never are 100% representative. The accuracy can only be raised by carefully selecting the samples and increasing their number.

2. All additionally occurring processes are neglected. Consider this especially with waterlogging soils!
3. The ratio $N_2/N_2O$ is entered to the soil respiration. ⇐ In the following this error will propagate to the calculation of the nitrification rate. This error is small if the denitrification rate is small.
4. For the calculation of the nitrification a respirator coefficient of 1 is assumed. As the soil respiration rate normally is relatively large, even little deviations can cause a relatively large error in the nitrification rate.
5. The ratio autotrophic/heterotrophic nitrification is not measurable and therefore must be accepted.
6. The exchange of the soil gas with the headspace gases will never be complete.

### 9.1.9 Notes to error calculation

- The not systematic errors (sensor errors) are considered to be typical but not severe. If the absolute values are not exactly known, plausible values are used for the calculation.
- In sums the absolute values are added as root sum square values.
- In multiplications the relative errors are added as square values.
- The systematic errors cannot be captured by the error calculation. In case the user has to estimate them himself.

### 9.1.10 Headspace measurement

The assumed error for the absolute pressure is 5 hPa (=$\Delta p$). When 10 ml is withdrawn the pressure will decrease for approx. 10 to 12 hPa This pressure difference can be measured as precise as 0,2 hPa (=$\Delta p_h$). The typical error of an syringe is approx. 1%. Then, all errors have about the same quantity. The headspace can be determined with an accuracy of 2%.

Both accuracies ($\Delta p$ and $\Delta p_h$) of the pressure measurement cannot be adjusted by the user.

## 9.1.11 Water content

The water content can be determined with two methods.

1. By the water content of a known soil sample volume.
2. By the weight of a moist and a dry soil.

As the water content cannot be measured better than 2 vol%, even with special moisture probes, the second method is much more precise and therefore, should be applied. Also, the results are based on the true weight.

For the determination of the soil dry weight the sample is dried in an oven for at least 24h at 105 °C. (As recommended for example by [HAR 1992].)

Error calculation for method 1:

$$\Delta V_{aq} = V_{aq} \cdot \sqrt{\left(\frac{\Delta V_{bs}}{V_{bs}}\right)^2 + \left(\frac{\Delta WG}{WG}\right)^2}$$

Error calculation for method 2:

$$\Delta M_{aq} = \sqrt{\Delta M_{Bod.f}{}^2 + \Delta M_{Bod.t}{}^2}$$

## 9.1.12 Dissolved gases

### 9.1.12.1 Partial gas pressure

The partial gas pressure is required for the calculation of the solution of the gases in the soil water. The error for the partial pressure of $CO_2$ is described below. The calculation for oxygen is the same.

$$\Delta p_{CO_2} = p_{CO_2} \cdot \Delta Vol\%_{CO_2}$$

The error in vol% cannot be adjusted by the user. For $CO_2$ the error is 0,02 vol%, for oxygen 0,03 vol%.

These errors are related on the stability of the sensors during a typical measuring time of 5 to 10 hours. In the following calculations they are entered into the estimation for the second term in the root.

### 9.1.12.2 Dissolved carbon dioxide

The amount of dissolved gas in the water has an linear dependence on the quantity of water and on the partial pressure of the relevant gas. More complex is the dependence on temperature which is determined experimentally and expressed with the Henry constant. Despite it is called a constant there is an dependence on temperature. For the BaPS calculation this function is approximated by an polynomial.

Another error source is that the partial pressure throughout the soil is not exactly the headspace pressure everywhere.

These error are expressed by:

$$\Delta CO_{2,gel} = \left| CO_{2,gel} \cdot \sqrt{\left(\frac{\Delta V_{aq}}{V_{aq}}\right)^2 + (0{,}04)^2} \right|$$

The second term (4% relative error) includes an estimate of the error of the $CO_2$ probe, the error for calculating the Henry constant (approx. 1%) and the inaccuracy regarding the constancy of the partial pressure throughout the soil sample. The last one can be adjusted by the user in the register "Special Parameters“ ⇐ "Error of dissolved gases “.

### 9.1.12.3 Dissolved oxygen

The calculation is analogous to the calculation of dissolved $CO_2$, whereas the estimated error is larger due to the less accuracy of the oxygen sensor.

$$\Delta O_{2,gel} = \left| O_{2,gel} \cdot \sqrt{\left(\frac{\Delta V_{aq}}{V_{aq}}\right)^2 + (0{,}07)^2} \right|$$

As the solubility of $CO_2$ is much higher than of $O_2$ the calculation error is much less crucial for dissolved $O_2$.

## 9.1.13 Gas concentrations

For calculating the amount of $O_2$ the sensor reading (in vol%) must be transformed into a concentration with the following error:

$$\Delta Konz = Konz \cdot \sqrt{\left(\frac{\Delta Vol\%}{Vol\%}\right)^2 + \left(\frac{\Delta p}{p}\right)^2 + \left(\frac{\Delta T}{T + 273{,}15}\right)^2}$$

The errors in the concentration changes which are required for the conversion rates are

- for $CO_2$ approx. 2%
- for $O_2$ approx. 4%

## 9.1.14 Gas conversion rates

$CO_2$

$$\Delta dCO_2 = \sqrt{\left[V_{head}\left(Konz_{CO_2}(t_2) - Konz_{CO_2}(t_1)\right)\sqrt{\left(\frac{\Delta V_{head}}{V_{head}}\right)^2 + \left(\frac{\Delta Konz_{CO_2}}{Konz_{CO_2}(t_2) - Konz_{CO_2}(t_1)}\right)^2}\right]^2 + \Delta CO_{2,gel}{}^2}$$

$O_2$

$$\Delta dO_2 = \sqrt{\left[V_{head}\left(Konz_{O_2}(t_2) - Konz_{O_2}(t_1)\right)\sqrt{\left(\frac{\Delta V_{head}}{V_{head}}\right)^2 + \left(\frac{\Delta Konz_{O_2}}{Konz_{O_2}(t_2) - Konz_{O_2}(t_1)}\right)^2}\right]^2 + \Delta O_{2,gel}{}^2}$$

Total gas (pressure measurement)

$$\Delta dn = \sqrt{\left[\frac{100 \cdot V_{head}}{R} \cdot \left(\frac{p(t_2)}{T(t_2) + 273{,}15} - \frac{p(t_1)}{T(t_1) + 273{,}15}\right)\sqrt{\left(\frac{\Delta V_{head}}{V_{head}}\right)^2 + \left(\frac{\Delta p(t,T)}{p(t_2,T) - p(t_1,T)}\right)^2}\right]^2 + \Delta CO_{2,gel}{}^2 + \Delta O_{2,gel}{}^2}$$

The conversion rate gets more precise the larger the changes of the readings are. The factor $\Delta p(t, T)$ in the total gas amount error calculation is the possible accuracy for measuring the temperature compensated pressure. For BaPS this factor is 0,1 hPa. To achieve the preferable accuracy of 2% for the pressure change measurement, a pressure change of 5 hPa must be measured.

## 9.1.15 Denitrification

The accuracy with which the developing nitrogen compounds ($N_2$ and $N_2O$) can be measured, is:

$$\Delta dNO = \sqrt{\Delta dn^2 + \Delta dCO_2{}^2 + \Delta dO_2{}^2}$$

Thus, the error for calculating the denitrification rate is:

$$\Delta k_{den} = \left| k_{den} \cdot \sqrt{\left(\frac{\Delta dNO}{dNO}\right)^2 + \left(\frac{\Delta M_{Bod,t}}{M_{Bod,t}}\right)^2} \right|$$

Here, the error for the determination of the soil dry weight is entered as well. This explains again why this parameter should be determined directly.

### 9.1.16 Soil respiration

Error of the CO2 balance of denitrification:

$$\Delta dCO_{2,den} = \left| dCO_{2,den} \cdot \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta dNO}{dNO}\right)^2} \right|$$

Here, the factor X which is set by the user is needed (see chapter "Calculus" – "Soil respiration"). Error in the CO2 balance of nitrification:

$$\Delta dCO_{2,nit} = \left| dCO_{2,nit} \cdot \sqrt{\left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\sqrt{\Delta dn^2 + \Delta dCO_{2,den}{}^2 + \Delta dNO^2}}{dn - dCO_{2,den} - dNO}\right)^2} \right|$$

Here, the factor Y which is set by the user is needed (see chapter "Calculus" – "Soil respiration"). Then, the error of the CO2 conversion of soil respiration can be calculated as:

$$\Delta dCO_{2,res} = \sqrt{\Delta dCO_2{}^2 + \Delta dCO_{2,nit}{}^2 + \Delta dCO_{2,den}{}^2}$$

The calculation error for the soil respiration rate then is:

$$\Delta dCO_{2,res} = \sqrt{\Delta dCO_2{}^2 + \Delta dCO_{2,nit}{}^2 + \Delta dCO_{2,den}{}^2}$$

## 9.1.17 Nitrification rate

The error in the calculation of the oxygen conversion by nitrification is:

$$\Delta dO_{2,nit} = \sqrt{\Delta dO_2{}^2 + \left( \frac{dCO_{2,res}}{RK} \cdot \sqrt{\left( \frac{\Delta dCO_{2,res}}{dCO_{2,res}} \right)^2 + \left( \frac{\Delta RK}{RK} \right)^2} \right)^2}$$

Finally, the error of the calculated nitrification rate is:

$$\Delta k_{nit} = \left| k_{nit} \cdot \sqrt{\left( \frac{\Delta dO_{2,nit}}{dO_{2,nit}} \right)^2 + \left( \frac{\Delta M_{Bod,t}}{M_{Bod,t}} \right)^2} \right|$$

## 9.1.18 Setups before a measurement

| | | |
|---|---|---|
| $\Delta V_{sp}$ | ml | Syringe volume (millilitres) |
| $\Delta$WG | % | (Estimated) error of water content |
| $\Delta$aut/het | | Error in the ratio of autotrophic and heterotrophic nitrification |
| $\Delta N_2/N_2O$ | | Error in the ratio of $N_2/N_2O$ for denitrification |
| $\Delta V_{bs}$ | ml | Soil sample volume (millilitres) |
| $\Delta$CO2Henry | | Added-up errors for calculation of dissolved $CO_2$ |
| $\Delta$O2Henry | | Added-up errors for calculation of dissolved $O_2$ |
| $\Delta M_{Bod,f}$ | | Error for the initial weight of the moist soil |
| $\Delta M_{Bod,t}$ | | Error of the soil dry weight |

# 10 Malfunction diagnosis

| Problem | Solution |
|---|---|
| The difference of headspace and soil temperature is much higher than usual. | Check if the fan is working. To do so, open the lid and switch on the BaPS electronics. The fan should start now (the 24 pin plug must be connected). |
| No linkage of computer and BaPS electronics is possible. | Check if the interface cable is connected properly.<br>check if the electronic is supplied with power?<br>Check the setting of the COM-Port.<br>Check if the COM port is occupied by another program. |
| The $CO_2$ sensor continuously reads 3 vol%. | Check the sensor cable connection.<br>Had the sensor been connected to the BaPS electronic before switching on? If not, switch off the electronic and on again. |
| The BaPS measurement does not start. | Check if the selected configuration settings are reasonable (temperature stability)?<br>Check the function of the thermostat. |
| The BaPS cannot be switched on. | Check if the mains cable is connected.<br>Check the fuse. |
| The sensor readings are garbage. | Check the sensors' power supply.<br>Check if the calibration specifications are correct. |

# 11 Technical specifications

## 11.1 Electronics

| | |
|---|---|
| Analogue inputs | 8, differential, 0...2,5 VDC |
| Digital I/O-Ports | 8, TTL |
| A/D transformation | 24 bit |
| Accuracy | 0,05 % |
| Interface | RS232 |
| Cable length | 2 m |
| Mains power supply | 115/230 VAC |
| Fuse | 1 A, quick-acting fuse |
| Current consumption | max. 500 mA |
| Enclosure: | |
| Width | 255 mm |
| Height | 160 mm |
| depth | 260 mm |
| Protective rate | IP 20 |
| Working temperature | 5 ... 35 °C |
| Storage temperature | -20 ... 70 °C |

## 11.2 Hardware

Technical specifications:

| | |
|---|---|
| Connector CO2 sensor | PG 11 |
| Connector pressure sensor | G 1/4 |
| Connector septum | G 1/4 |
| Connector cooling fluid | Quick-lock coupling, for tubes with 6,4 mm inside diameter |
| Sampling rings size: | Standard |
| Height | 40,5 mm |
| Diameter | I. D. 56 mm, O. D. 60 mm |
| Volume | 100 ml |
| Housing: | |
| Diameter | approx. 234 mm, without tube couplings |
| Height with sensor head + sensors | ca. 280 mm |
| Height with transportation lid | 97 mm |
| Material | Aluminium, anodized |
| Weight without sampling rings: | |
| with sensor head | approx. 6,5 kg |
| with transportation lid | approx. 5,0 kg |
| Protective rate | IP 68 with closed transportation lid<br>IP 66 with closed sensor head |

## 11.3 Sensor technology

## 11.4 Carbon dioxide

The used $CO_2$ sensor is an infra-red absorption type, working with the single-beam method. The electronics which transfers the signal through the cable to the BaPS is integrated in the sensor head.

Technical specifications:

| | |
|---|---|
| Measuring range | 0 ... 3 vol% |
| Accuracy | 2 % |
| Measuring principle | IR absorption |
| Long term stability | 3 % / a |
| Temperature range | 0 ... 40 °C |
| Housing | |
| Material | Stainless steel |
| Diameter | 22 mm |
| Length | 100 mm |
| Connection | 8-pol. plug |
| Thread | PG 11 |
| Response time | 2 min |
| Calibration interval | 1 year |

## 11.5 Oxygen

Technical specifications:

| | | |
|---|---|---|
| Measuring range | vol% | 0 ... 25 |

| | |
|---|---|
| Accuracy | 1 % |
| Measuring principle | zirconium oxide , current limiting |
| Temperature range | 0 ... 50 °C |
| Housing | Integrated in BaPS sensor head |
| Response time | 10 min |

**The cable length between oxygen sensor and amplifier inside the BaPS may never be changed.**

## 11.6 Pressure

Technical specifications:

| | |
|---|---|
| Measuring range | 800 ... 1200 hPa |
| Accuracy | 0,1 % |
| Long term stability | 0,5 % / a |
| Measuring principle | Piezoresistive pressure transducer |
| Temperature range | 0 ... 50 °C |
| Housing | |
| Diameter | ca. 35 mm |
| Length | ca. 105 mm |
| Material | Stainless steel |
| Response time | 5 s |
| Calibration interval | 1 year |

Der Messverstärker ist in den Druckmesskopf integriert.

## 11.7 Temperature

For temperature measurement two PT1000 and one PT100 with the accuracy class 1/3 DIN B are used.

One sensor measures the headspace temperature. It is attached to the fan to have the most accurate result.

The two other sensors are integrated in an stainless steel tip and are pushed into the soil. The first is used by the BaPS, the second controls the external thermostat.

Technical specifications:

| | |
|---|---|
| Measuring range | -30 … 70 °C |
| Accuracy | 0,1 K at 0 °C |
| Measuring principle | Change of resistance of platinum |
| Housing | |
| Material | Stainless steel |
| Diameter | 5 mm |
| Length | 40 mm |
| Protective rate | IP 68 |
| Response time T 90 | 30 s |

## 11.8 System requirements

- Pentium 166 or higher (recommended)
- 8 MB RAM memory (recommended)
- 10 MB free space on hard-disk (necessary)
- Free RS232-interface (necessary)
- Graphic display: 800 x 600, 65.536 colours (recommended)
- Mouse (necessary)

# 12 Replacement parts and accessories

## 12.1 Replacement parts

### 12.1.1 BaPS calibration service

To assure the perfect performance of the BaPS process analysis system the sensors should be checked annually and, if necessary, be recalibrated. UMS offer this as an complete service (Art. no. BaPS-Kali).

### 12.1.2 Replacement parts list

| Article | Note | Art. no. |
|---|---|---|
| $CO_2$ sensor | incl. screw in housing and transducer | BaPS-CO2-3 |
| $O_2$ sensor | incl. transducer | BaPS-O2-25 |
| Pressure sensor | | BaPS-P-800-1200 |
| Quick-lock coupling, female with ∅6,4mm tube nipple | for external temperature regulation | BaPS-SCH-W |
| Reducing nipple for septum | VA stainless steel | BaPS-RED |
| Silicone septum 3mm, diameter12mm | 20 pieces | BaPS-SEP |
| Fork wrench 13/17 | for changing the septum | BaPS-GAB-13/17 |
| Fan | | BaPS-LÜF |
| BaPS container bottom | see accessories | |
| BaPS sensor head | incl. sensor installation | BaPS-SEN |
| BaPS transportation lid | | BaPS-TRA |
| Syringe 10 ml | | BaPS-SPR-10 |
| Spare needle for | | BaPS-SPR-ERS |

vacuum-tight syringe

| | | |
|---|---|---|
| Kaltgerätestecker | for supply of sensor interface | BaPS-KAL |
| RS 232 interface cable | | BaPS-RS232 |
| Thermo box | | BaPS-THE |
| Spare O-ring ring for sensor head | 3 pieces | BaPS-SEN-DICH |

# 12.2 Accessories

## 12.2.1 Cooling thermostat

UMS

# DC50 - K10

## Haake Refrigerated Circulator

This refrigerated circulator is equipped with a bath opening for direct temperature controlling samples. The built-in CFC-free cooling circuit enables efficient heat removal. This unit is often used to replace expensive tap water cooling.

**Features:**

- ✗ Robust design using high grade stainless steel and temperature resistant polymer with sealed bath cover
- ✗ Removable fan grid allows easy cleaning
- ✗ Bath is equipped with handles and drain opening
- ✗ 2-speed power-pump to reduce turbulences in open baths, wear-free
- ✗ Integrated overload protection
- ✗ User-resettable, adjustable overtemperature cut-out and low liquid level protection
- ✗ Easy to operate by only 4 navigation keys
- ✗ Electronic PID control using a highly sensitive Pt 1000 sensor for excellent temperature accuracy
- ✗ RS 232C interface as standard
- ✗ User-defined fixed temperatures with separate RTA for each temperature
- ✗ Display resolution selectable between 0.1 and 0.01 ° C
- ✗ Limitation of the usable temperature range by high and low temperature setting
- ✗ RTA = Real-Temperature-Adjustment
- ✗ User-adjustable correction factor to meet ISO 9004
- ✗ Alarm indication by FIS = Fault-Identification-System
- ✗ The reason for any malfunction is clearly displayed
- ✗ Built-in ETC (External Temperature Control) with a connection for an external Pt 100 sensor

*Technical Specifications*

| | |
|---|---|
| Bath volume max. | 3 L |
| Working temperature range | -10 to 150°C |
| Temperature accuracy | +/- 0.01 K |
| Cooling capacity at 20°C | 240 W |
| Heater capacity 230V | 2 kW |

| *Specification* | *Art. No.* |
|---|---|
| Haake DC50 - K10 | **DC50-K10** |

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## 12.2.2 Incubation container

UMS

# BaPS

**Incubator Container**

*Incubator container* *Art. No. BPK-100-S*

- Incubator, Ø 220 mm, h 67 mm
- Material: anodised aluminium
- 2 cooling water tube connectors for 6.4 mm tube
- 7 soil sample rings, Ø 60 x 56 mm, h 40.5 mm, volume 100 cc

*Incubator container* *Art. No. BPK-100-U*

- Incubator, Ø 220 mm, h 77 mm
- Material: anodised aluminium
- 2 cooling water tube connectors for 6.4 mm tube
- 7 soil sample rings, Ø 60 x 56 mm, h 40.5 mm, volume 100 cc

*Incubator container* *Art. No. BPK-250*

- Incubator, Ø 220 mm, h 77 mm
- Material: anodised aluminium
- 2 cooling water tube connectors for 6.4 mm tube
- 3 soil sample rings, Ø 84 x 80 mm, h 50 mm, volume 250 cc

GEPRÜFTE UMS QUALITÄT

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## 12.2.3 Set of sampling rings for undisturbed soil sampling

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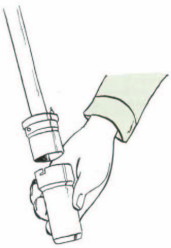
# Sampling Ring Set

The soil sample ring is placed in a closed ring holder.



**Sample ring kit, for all soils to a depth of up to 2 m**

The sample sets with a postfix SC can be used to take samples in virtually all soils. The samples can be taken on the surface, in auger holes or in profile pits, above as well as under the groundwater level. The closed ring holder in this set is fitted with a conical threaded connection which means that the ring holder may also be hammered into the soil with an impact absorbing hammer.

The set, among other items, contains: a closed ring holder, a handle with beating head, an Edelman- and a Riverside auger, extension rods, a hammering head with a guide cylinder, an aluminium case with soil sample rings and various accessories.

The samples sets with the postfix SC can be obtained for soil sample rings with a diameter of 53, 60 and 84 mm. The most commonly applied (standard) diameter is 53 mm.

## Soil sample rings

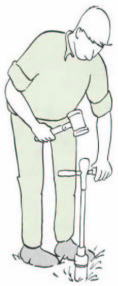
Soil sample rings are stainless steel rings made of seamless tubes, smooth inside and out. The bottom of the ring has a cutting edge. The dimensions, and thus the volume content, of soil sample rings are exactly known, which makes them highly suitable for laboratory studies. With soil sample rings undisturbed samples are taken.

These are then used for, for example:

- The moisture content at various moisture tensions, from which a pF-curve can be made.
- The water permeability.
- The air permeability.
- The weight by volume.
- The density.
- The soil-water-air relationship at field capacity.
- The pore distribution.
- The oxygen diffusion.

Soil sample rings are transported in special aluminium cases, strong and resistant against humidity and heat.

The soil sample ring is hammered into the soil applying an impact absorbing hammer.



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The soil sampling ring is hammered into the soil from the surface using an impact absorbing hammer and guide cylinder.

## Open ring holder

In case of an open ring holder, the ring is locked in the holder by means of a lever.
Over the ring about 4 cm headroom is left, allowing for an oversize sample to be taken.

Advantages of the ring holder are:
- The soil sample ring is very easily replaced.
- The ring holder is relatively insensitive to dust and dirt.
- Little resistance to penetration.

Disadvantages of the ring holder are:
- The sample is not oversized at the bottom end of the ring.
- In very weak soils, or below the water table, there is a great risk of the sample falling out of the ring.
- Sample rings may be lost through being overloaded and/or being incorrectly clamped.
- Because the sample ring is not protected, it can be damaged.

## Closed ring holder

With this type of ring holder, the soil sample ring is placed in a cutting shoe. The ring is clamped inside the cutting shoe and no water or soil can come into the ring from the top side.
Advantages of this ring holder are:
- The sample is oversized on both sides.
- No risk of losing a sample.
- The sample ring is in a protected position inside the cutting shoe, there is no risk of losing or damaging the ring.

## Hammering head with guide cylinder

The hammering head with guide cylinder is used for filling soil sample rings in hard soil layers both on the surface and in profile pits. The sample ring is clamped to the hammering head by means of a retaining ring. The guide cylinder ensures that the sample is taken in a true straight line. The soil sample ring can simply be dug out or extruded using the bent spatula.

The sample is trimmed using a small frame saw.

| Soil Sampling Set | Art. No. BPK-250 |
|---|---|
| Ø 60 x 56 mm, h 40.5mm, volume 100 cc | bpe.07.60.SC |
| Ø 53 x 50 mm, h 51 mm, volume 100 cc | bpe.07.53.SC |
| Ø 84 x 80 mm, h 50 mm, volume 250 cc | bpe.03.84.SC |

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## 12.2.4 Further accessories

| Article | Note | Art. No. |
|---|---|---|
| Filler cylinder for sampling rings | | BaPS-BLI-3 |
| Sampling rings | | on request |
| Protective caps for sampling rings | | on request |
| System training at your laboratory | | BaPS-SYS |

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The IFU has applied the patent for the BaPS Barometric Process Separation. – the company UMS-GmbH is the only license holder for this system.